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ALTERNATIVES FOR UPGRADING OR CLOSING ARMY LANDFILLS CLASSIFIED--ETC(U)

FEB 82 C WIEGAND, G GERDES, B DONAHUE

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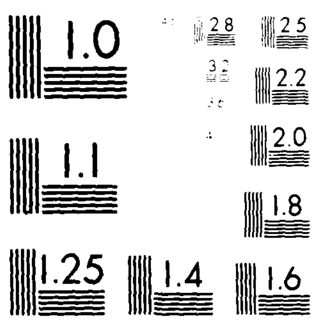
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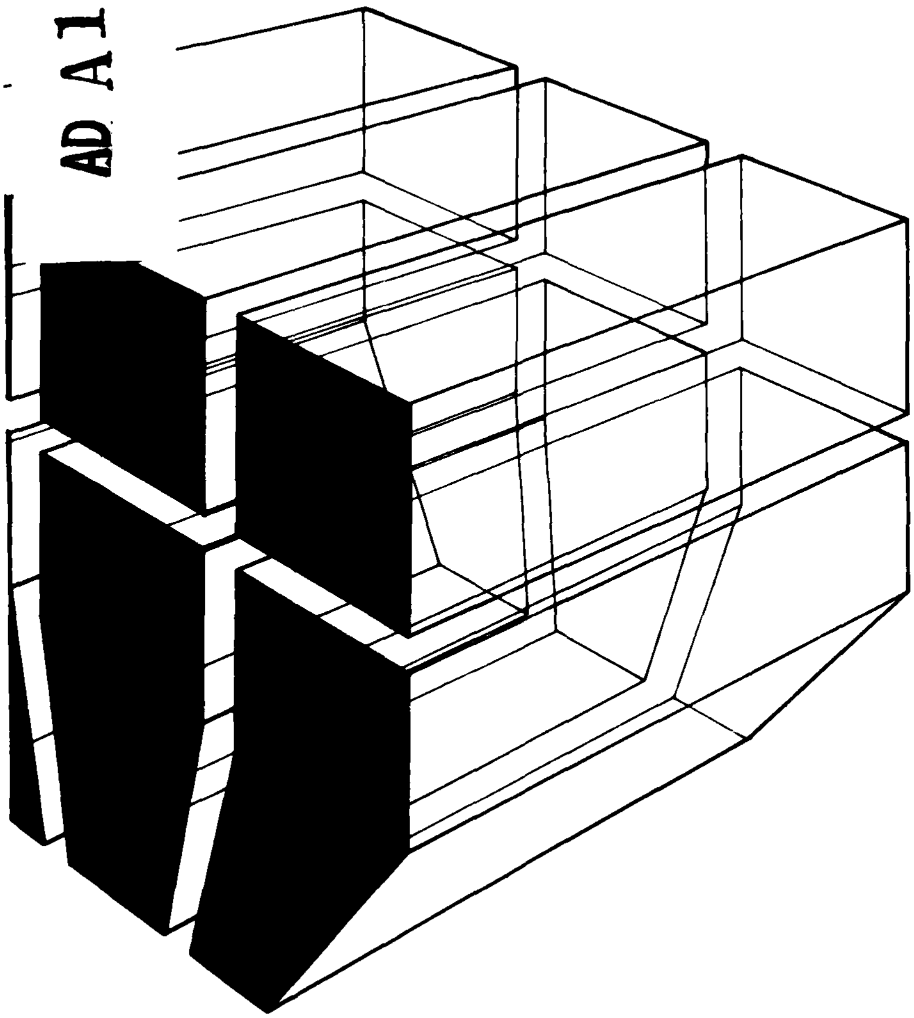
Technical Report N-123
February 1982
Solid Waste Management, Recycle, Resource
Recovery for Military Facilities

ALTERNATIVES FOR UPGRADING OR CLOSING ARMY LANDFILLS CLASSIFIED AS OPEN DUMPS



by
C. Wiegand
G. Gerdes
B. Donahue

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Some landfills on Army installations may be classified "open dumps" during the land disposal site inventory mandated by the Resource Conservation and Recovery Act (RCRA). Therefore, Facilities Engineers (FEs) will have to choose among several technologies for upgrading or closing these sites to comply with the new RCRA criteria.

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This report describes each alternative technology, discusses its advantages and disadvantages, explains the type of labor and equipment needed, and gives costs that the FE can use to make order-of-magnitude estimates and to compare specific alternatives for upgrade.

FOREWORD

This work was performed for the Office of the Chief of Engineers (OCE) under Project 4A762720A896, "Environmental Protection Techniques in Military Construction"; Task E, "Environmental Source Reduction, Control and Treatment"; Work Unit 005, "Solid Waste Management, Recycle, Resource Recovery for Military Facilities." Mr. Rick Newsome, DAEN-MPO-D, was the OCE Technical Monitor.

This report was prepared by JRB Associates, Inc., for the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (CERL). Dr. R. K. Jain is Chief of EN.

Also providing input were: F. A. Bizzoco, OCE; R. Nichols, U.S. Army Forces Command; M. B. Poulson, U.S. Army Training and Doctrine Command; P. G. Malone, A. J. Green, and N. R. Francingues, U.S. Army Engineer Waterways Experiment Station; D. Corbitt, U.S. Army Environmental Hygiene Agency; and Dr. E. Novak, W. Mikucki, and R. Fileccia, CERL.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The Resource Conservation and Recovery Act of 1976 (RCRA) has mandated that the Environmental Protection Agency (EPA) make an inventory of all landfill disposal sites in the United States. State agencies must classify the sites for solid waste as either open dumps or sanitary landfills. If a land disposal site is classified an open dump, it must be closed or upgraded to a sanitary landfill.

No Army regulations or technical manuals now provide guidance on upgrading or closing landfills. Therefore, the Office of the Chief of Engineers asked the U.S. Army Construction Engineering Research Laboratory to compile the information Facility Engineers (FEs) need to choose among upgrade and closure alternatives.

Objectives

The objectives of this report are: (1) to provide FEs technical information on upgrading and closing landfills classified as open dumps; and (2) to give cost information which will allow the FE to compare alternative methods of upgrading a noncomplying site.

Approach

The information in this report was gathered by a search of the literature on remedial actions at waste disposal sites, and by field surveys at operating and closed landfills. The three major sources used in compiling costs were: Means Building Construction Cost Data, Remedial Action Alternatives for Municipal Solid Waste Landfill Sites, and Manual for Remedial Actions at Waste Disposal Sites.[1] Means data were used whenever possible to ensure consistency, but in cases of limited data application, one of the alternate sources was consulted.

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[1] Building Construction Cost Data: 1980, 38th ed. (Robert Snow Means Company, Inc., 1979); W. W. Beck, Jr., Remedial Action Alternatives for Municipal Solid Waste Landfill Sites (A. W. Martin Associates, Inc., 1978); Manual for Remedial Actions at Waste Disposal Sites (JRB Associates, Inc., 1980).

Scope

Because of the wide variations in site conditions faced by different installations, this report is not intended as an engineering/construction manual, nor is it designed to provide an exact cost for upgrading individual sites. Rather, it provides the FE with a basis for making a preliminary decision about any site. It should also be noted that the information in this report applies only to municipal waste landfills; it is not applicable to sites containing explosives or industrial organics.

Use of This Report

In this report the technologies for upgrading or closing landfills are organized according to the RCRA Section 4004 criteria published in the 13 September 1979 Federal Register. For each remedial action, there is a brief discussion and illustration of the technology, an estimate of the overall cost of that technology, and an explanation of the type of labor and equipment required to perform the construction.

A brief discussion of the advantages and disadvantages of these technologies provides the user a realistic appraisal of each application. Often, a technology can be used to solve more than one problem. (For example, liners can be used to control the impacts of surface water, groundwater, and gases.) When this is the case, the technologies are cross-referenced.

The costs in this report can be used to make order-of-magnitude estimates to compare specific alternatives for upgrade.* A simple procedure is followed to estimate costs:

1. Determine needed scope of work for remedial activity and derive unit multipliers, usually in terms of length, area, or volume, depending on the particular remedial action

2. Outline necessary construction activities

3. Assign costs per activity and apply multipliers

4. Determine total construction costs.

If non-Army personnel are used for design and construction, a 9 percent engineering fee and 15 percent contingency costs will have to be added to the total construction expense to figure total capital costs. Note that it has been assumed that most heavy equipment is available; the costs of acquisition are not included in the estimates.

* Note that all cost estimates are listed with 1980 as the base year. Local conditions must be considered and inflation factors used for each application.

The operation and maintenance (O&M) costs for each system have not been included in the cost estimates. All upgrading technologies discussed in this report require at least periodic inspections and minor maintenance. For example, a diversion structure may have to be rebuilt and replanted in sections because of animal burrowing and subsequent unpredicted erosion. All mechanical system alternatives described will require preventive and scheduled maintenance activities. In addition, energy costs must be considered. Significant O&M costs have been noted, and methods of estimating these expenses are included in Appendix A.

The specific characteristics and location of the site have a significant impact on the costs associated with a particular alternative. For example, the absence of native clay will increase the cost of constructing levees, and the soil type at the site will influence the cost of erosion control and compaction.

Table 1 is a quick reference to the upgrading technologies that the FE can use to make a landfill comply with RCRA's Section 4004 criteria.

Mode of Technology Transfer

The information in this report will impact on Army Regulation (AR) 420-47, Solid Waste Management.

2 FLOODPLAINS

According to the floodplains criterion under RCRA's Section 4004, landfills in 100-year floodplains must be improved to protect against washout. In addition, the land disposal site, as upgraded with dikes, berms, or other improvements, must not restrict normal overflow patterns, and thereby increase flooding elsewhere along the stream.

There are two strategies for complying with the Section 4004 floodplains criterion. One involves establishing barriers which prevent floodwaters from entering the landfill; the other allows floodwaters to enter the site, but prevents surface material from being washed out with receding waters. Figure 1 shows a typical decision flow for selecting diversion techniques and washout prevention measures. This diagram can be followed to determine which site-specific circumstances will require a particular upgrade technology.

Diversion Systems

Diversion systems are barriers such as levees, berms, and flood walls, which can be built to prevent floodwaters from entering the landfill. Diversion systems are made either of earthen materials with or without a clay core, or of concrete. The design is determined by the size of the 100-year base flood, the size of the landfill, land availability, and the landfill's operational design. There may be additional costs for berms and levees since these barriers may have to be rebuilt or regraded and planted after the floodwater has receded.

Cost Estimates for Levees

Table 2 gives the costs for a typical levee design (Figure 2).

Cost Estimates for Floodwalls

Prices were developed for two different floodwall designs -- gravity concrete and reinforced concrete cantilever. Both designs are 10-ft high and have a 33 degree surcharge. The costs include excavation and backfill but not additional site preparation (Table 3).

Cost Estimates for Control of Backwater Flow

The dredging of areas to increase backwater flow depends entirely on local conditions, including bank type, river flow and velocities, type of soil, and vegetation. Because of these factors, detailed unit costs could not be derived. Instead, expected costs per unit of the various activities are listed in Table 4. Once the type of dredging, and the amount and type of excavation are known, the unit costs can be used to arrive at expected capital costs.

Advantages/Disadvantages

Table 5 lists the advantages, disadvantages, and restrictions in using diversion systems to prevent washouts during floods.

Dredging costs for diversion systems may vary substantially depending on bank type, river flow and velocity, type of soil, and vegetation.

Washout Prevention

Several technologies can prevent the washout of waste materials from landfills during floods: gabions, fabric barriers, and other revetments. These structures can handle heavy or sustained flows; however, infiltration barriers must be used with washout prevention techniques (see the discussion of surface water and groundwater controls in Chapters 4 and 5).

Table 6 gives costs for gabions, a typical washout control technique. Site preparation expenses, which vary widely, are not included.

Table 7 lists advantages, disadvantages, and restrictions in using washout prevention techniques. Before using these methods, the FE should consider fully the characteristics of stream flow, including the frequency of heavy and sustained flow, and flood storage.

3 ENDANGERED SPECIES

According to the endangered species criterion of RCRA's Section 4004, the landfill facility, or remedial actions, must not kill endangered species, and must not eliminate nor damage their critical habitat. Recommendations for remedial actions are difficult to make because solutions are site-specific — determined by the size and type of landfill, the species requiring protection, and many other variables. Complete listings of the endangered and threatened wildlife species and the specifications for their protection are in 50 CFR 17.11.

Generally, the options available for protecting endangered species are:

1. Selective landfilling, in which portions of the landfill area are reserved for the species' habitat

2. Mitigation land, which compensates for the loss of the ecological value of the land by providing other land of the same characteristics as that being lost to landfilling

3. Deep or vertical landfilling, which minimizes the area of the land being filled by making the disposal area as deep as possible.

Each of these must be reviewed before costs can be estimated since the selection of an option must be based on land availability and amount of critical habitat (Figure 3). Generally, acquiring mitigation land can be expected to be most expensive because experience has shown that two parcels of new land will be needed to replace each parcel of original habitat. Additional costs can be anticipated for legal and administrative services for transfer of land parcels, biological studies, and regrading or revegetation.

4 SURFACE WATER

The surface water criterion of Section 4004 requires that the disposal site, as upgraded, not discharge pollutants into surface waters in violation of the National Pollutant Discharge Elimination System (NPDES) permit requirements of Section 402 of the Clean Water Act (CWA); that the disposal site not discharge dredged or fill material into surface waters in violation of Section 404 of the CWA; and that the disposal site not cause non-point runoff in violation of the CWA Section 208 water quality management plan.

An active landfill operation may directly affect surface water quality in two ways. First, runoff, carrying sediment or solid wastes from bare landfill surfaces, adds to the turbidity and nutrient levels of surface water. Second, contaminated leachate reaches the body of water -- either directly, as seepage runoff or seepage from a contaminated aquifer into a stream below surface water level, or indirectly, as surface runoff.

Important considerations in selecting the appropriate upgrade technology include topography, geologic and hydrologic conditions, amount of water, and degree of contaminants. Before taking remedial action, the FE must see whether NPDES permits and Dredge and Fill Permits are needed. If a waterway is channeled or directed, for example, these permits must be obtained. Figure 4 illustrates the process for selecting surface water protection techniques. Options for remedial action are discussed below.

Ditches

Ditches (or swales) are temporary drainage ways excavated above and below disturbed areas to intercept and divert runoff. They may be dug along the up-slope perimeter of disposal areas to intercept storm runoff and carry it to natural drainage channels down-slope of the site. As shown in Figure 5, ditches may also be installed down-slope of covered disposal sites to collect and transport sediment-laden flow to sediment traps or basins. Ditches should be left in place until the disposal site is sealed and stabilized with cover vegetation.

Table 8 gives the costs for a typical ditch design: 12-ft wide at the top, with walls sloping in 2:1 to 4-ft wide at the bottom, with a total depth of 2 ft.

The advantages, disadvantages, and restrictions in using ditches for protecting surface waters are listed in Table 9.

Ditches should be used to divert surface runoff only when the slope of the landfill is less than 15 percent. Otherwise, the ditches become very difficult and expensive to maintain.

Diversions

Diversions are permanent or temporary shallow drainage ways excavated along the contour of graded slopes, with a supporting earthen ridge (dike or berm) constructed along the downhill edge of the drainage way. Essentially, a diversion is a combination of a ditch and a dike.[2] Diversions are used primarily for permanent erosion control on long slopes subject to heavy flow, and may be constructed to divide long slopes into nonerosive segments. Diversions may also be built at the top or at the base of long graded slopes at disposal sites to intercept and carry flow at nonerosive velocities to natural or prepared outlets (e.g., level runoff spreaders).

For the costs of diversions, see the estimates for ditches in Table 8.

Table 10 lists the advantages, disadvantages, and restrictions in using diversions.

Table 11 presents the maximum permissible design velocities for flow in diversion ditches and ground waterways, based on the channel grade and stabilizing cover material.

Diversions are recommended for use only on slopes of 15 percent or less.

Benches/Terraces

Terraces and benches are relatively flat areas built along the contour of very long or very steep slopes to slow runoff and channel it into ditches or diversions so that it is carried off-site without causing erosion. These structures are also known as bench terraces or drainage benches.

Although benches and terraces are slope reduction devices, they are generally constructed with reverse fall or natural fall to divert water to stabilized drainage ways (Figures 6 and 7). Benches and terraces may be used to break the steeply graded slopes of covered disposal sites into less erodible segments. Up-slope of the disposal site, they slow and divert storm runoff around the site. Down-slope of landfill areas, they intercept and divert sediment-laden runoff to traps or basins.

Costs have been prepared for a trench 6-ft wide at the top, 1.5-ft deep, with walls sloping 2:1 to the bottom (Table 12). It is constructed by building up the earth cover of the down-slope shelf.

Table 13 lists the advantages, disadvantages, and restrictions in constructing benches and terraces for controlling surface runoff.

Benches and terraces can be used most effectively on very steep or very long slopes and in areas where high precipitation rates create heavy surface runoff.

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2 Erosion and Sediment Control: Surface Mining in the Eastern United States, EPA Technology Transfer (U.S. Environmental Protection Agency [EPA], 1976).

Chutes and Downpipes

Chutes and downpipes are used to carry concentrated runoff flows from one level to another. Chutes (or flumes) are open channels, normally lined with bituminous concrete, Portland cement concrete, grouted rip-rap, or similar nonerodible material. These structures may be useful in handling runoff on long, steep slopes at disposal sites. Downpipes (downdrains, pipe slope drains) are temporary structures made of rigid piping (such as corrugated metal) or flexible tubing of heavy-duty fabric (Figure 8). They are installed with a standard prefabricated entrance section and are designed to handle flow from drainage areas of 5 acres or smaller. Like paved chutes, downpipes discharge to stabilized outlets or sediment traps. Downpipes may be used to collect and transport runoff from long, isolated outslopes or from small disposal areas along steep slopes.

Cost Estimates for Paved Chutes

Chute designs depend on areas of drainage. The costs in Table 14 were developed for a drainage area of 18 acres. The chute is 10-ft wide at the bottom, 1-ft deep, with walls sloping down 1.5:1. Included are costs of rip-rap stabilization bed (1.5-ft high x 6-ft long x 24-ft wide). The costs of end flumes are not included. The typical total cost for a 100-yd chute system is $3000 to $6000.

Cost Estimates for Downpipes

Costs were developed for a corrugated metal downpipe to drain the area behind a dike wall (Table 15). It was assumed that between 0.25 and 1.00 cu yd/linear yd (cy/ly) excavation was typical for this construction. Included are costs of rip-rap stabilization apron (1-ft high x 9-ft long x 18-ft wide). The typical total cost for a 100-yd downpipe system is $10,000 to $12,000. There may be additional costs if much diking reconstruction is necessary for installation.

Advantages/Disadvantages

Table 16 lists the advantages, disadvantages, and restrictions in using chutes and downdrains.

Special Site Considerations

Chutes and downdrains are rather expensive to construct and maintain, and should be used only where the area is too steep for benches, terraces, diversions, or ditches.

Drainage Systems

Gravity drainage systems are designed to remove a specific volume of water from a disposal site in a given length of time. They consist of a filter, a collector or series of collectors, and a basin or sump for disposal of the collected water (Figure 9).

A drainage system can help the FE achieve several objectives. Most frequently, it is used to intercept runoff and infiltration from a site, and to dispose of or treat the water downgradient of the site. A drainage system may also be used to intercept water around the site and to lower groundwater elevation slightly.

Frequently, the collectors or recharge basin are used with other remedial techniques. Collectors may discharge to a treatment system if the water drained from the site is contaminated. A recharge basin may be used with a groundwater pumping and treatment system to recycle the treated water.

The design of a drainage system depends on the drainage characteristics of the soil, the extent to which drainage is needed, and the length of time the system will operate. Drainage capabilities of the soil depend on soil permeability, consolidation, and shrinkage.[3]

The filter is a porous material which prevents movement of the soil into the drains, but is pervious enough to offer little resistance to seepage. Filters are generally designed to restrain only the coarsest 15 percent of the soil. As the coarse sands collect over the filter openings, their voids in turn create small openings to trap even smaller soil particles.

Cost Estimates for Gravel-Filled Trenches

Costs were developed for a gravel-filled trench 10-ft deep (8 ft of gravel, 2 ft of topsoil) x 3-ft wide, lined with synthetic fabric (Table 17).

Cost Estimates for PVC Piping/Trench Systems

Table 18 lists costs for 4-in. perforated polyvinyl chloride (PVC) pipe laid in a 1.5-ft wide x 6-ft deep (5-ft gravel) trench. The pipes drain to a header pipe or sump. Costs for collection are not included.

Advantages/Disadvantages

Table 19 lists the advantages, disadvantages, and restrictions in using drainage systems.

Sedimentation Ponds

Collected surface runoff from the landfill usually carries large amounts of silt, which must settle out before the runoff is discharged into a body of surface water. This settling is done in holding or sedimentation ponds. A typical design for a sediment basin embankment is presented in Figure 10. A professional engineer or hydrologist should design holding ponds to have enough capacity during storms, when erosion may be most severe. Field manuals provided by regional offices of the U.S. Soil Conservation Service are helpful in determining the most effective erosion protection methods for individual sites.

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3 G. B. Sowers and G. F. Sowers, Introductory Soil Mechanics and Foundations, 3rd ed. (Macmillan & Co., 1970), p 183.

A variety of excavation techniques, with a wide range of costs, may be used. The costs in Table 20 have been developed using the lowest and highest priced methods to give this range.

Table 21 lists the advantages, disadvantages, and restrictions in using sedimentation ponds and basins.

Grading and Planting

Landfill slopes must be graded to improve runoff while minimizing erosion. The final grade of a landfill should prevent water from ponding, but should not exceed 30 percent. A minimum slope, including terraces, of 2 percent is recommended. By carefully designing landfill surface gradients, and selecting the correct vegetation, and soil type and thickness, the FE can minimize or prevent infiltration.

For constructing final slopes, clay or silty clay soils are preferable because of their resistance to erosion and infiltration when compacted. Sandier soils erode more quickly and allow greater infiltration into the landfill.

Unit costs for regrading and revegetation are presented in Table 22. A further breakdown is possible only when the type and amount of regrading and revegetation are known.

Table 23 lists the advantages, disadvantages, and restrictions in grading and planting.

Table 24 shows the effect of several plants on the water of the landfill.

Surface Capping

A surface cap must be put in place after landfilling in any area has been completed. A cap reduces or eliminates infiltration, thereby limiting leachate production. In addition, the cap prevents movement of leachate to the surface. Surface lining or capping can be done with clays or synthetic membranes. Once a membrane is placed, it must be maintained to protect its integrity. If a clay is selected, it should have a permeability no greater than 1×10^{-7} cm/sec; a soil should have a liquid limit of at least 30, and a plasticity index of at least 15. Surface lining is a new concept that has been used infrequently.

When selecting natural or synthetic materials to seal or cap the surface, the FE should know the limitations of each. Clay is subject to cracking when it dries, settling, root decay, or root intrusion. On the other hand, synthetic barriers may be punctured or may fail because of faulty installation techniques, inferior product quality, or poor maintenance practices. Other disadvantages of capping include the difficulty of constructing an even, gently sloping top surface that is free of depressions which can hold rainwater. Clearly, the FE must follow proper installation and maintenance

procedures for these materials. Each product should be evaluated for cost and compatibility with disposal operations. Figure 11 illustrates various final cover alternatives.

Table 25 gives the costs for four different caps that are commonly used: clay, PVC membrane, bentonite cement, and bituminous concrete.

Table 26 summarizes the advantages, disadvantages, and restrictions in using synthetic and clay caps to control leachate production and movement.

If clay is not available on-site or nearby, the cost of transporting the material to the site will be very high. The other option is to use synthetic materials, but these will be expensive to purchase, install, and maintain properly.

Liners

Leachate may have to be totally contained in the landfill at sites where the effluent's generation cannot be kept at acceptable levels, and hydrogeologic conditions cannot minimize its impact on underlying groundwater. Typically, leachate can be contained if the refuse fill is surrounded by an impervious barrier or liner, creating a basin to hold any leachate produced.

Liner materials should have a permeability of 1×10^{-7} cm/sec, or less, and be able to resist physical and chemical attack by leachate. As a rule, the practical minimum thickness for natural soil liners is 5 ft, and for synthetic membrane liners, 20 mils. If synthetic liners are selected, their installation must be closely monitored.

The liner should be placed on a carefully prepared base of selected material that will prevent liner puncture while providing uniform, relatively unyielding support. As a rule it is prudent to scarify and recompact the base of the landfill to reduce or destroy all avenues of secondary permeability. A liner can be laid above this. The liner should be covered with material that will protect it from damage and to provide a drainage blanket for the leachate collection system when the liner is a base barrier. Generally, a soil layer about 2-ft thick effectively protects a liner from puncture.

Table 27 gives costs based on a 2-ft excavation, lined and filled for liner protection.

Table 28 summarizes the advantages, disadvantages, and restrictions in using synthetic and natural liner materials.

As with surface capping, the availability of clay on-site or nearby will determine whether the material can be used economically, or whether a synthetic liner will be needed.

Leachate Seep Control Systems

If leachate forms in the landfill, it may eventually exit on fill slopes, posing a threat to adjacent bodies of surface water. Leachate seeps on slopes

are caused when surface water infiltrates the cover, migrates downward until it encounters a less permeable intermediate soil layer or refuse lift, and then moves laterally until it seeps through thin or loose cover soil on a slope. Slope seeps can be prevented if leachate is kept from forming, but this cannot be done on all sites. The FE can control leachate seeps effectively by taking the following steps:

1. Removing the cover soil and several feet of refuse in the seep area

2. Placing a permeable layer of material to intercept the seepage

3. Installing a collector pipe in a trench from the seep area down the slope to a toe collection header or sump, where the leachate can be adequately managed

4. Replacing the cover soil over the permeable material and trench, and using a filter fabric between the cover soil and permeable material.

Figure 12 illustrates a typical control system for leachate seeps.

Leachate control is basically a specific application of a trench drainage system to areas that are displaying leachate seepage problems. See Drainage Systems for costs. Table 29 lists advantages, disadvantages, and restrictions in using leachate control systems.

5 GROUNDWATER

The groundwater criterion of Section 4004 protects underground drinking water sources -- aquifers supplying drinking water for human consumption, or containing less than 10 000 mg/L total dissolved solids. Landfills over such aquifers may not contaminate groundwater beyond the solid waste boundary (or an alternative boundary specified by the State, if a solid waste management plan has been approved). Contamination is defined as pollution beyond the limits specified in Appendix A of the Section 4004 criteria. Where these specified limits already have been exceeded, no additional contamination is allowed.

To prevent contamination of an underground drinking water source beyond the solid waste boundary, the adverse impacts of leachate must be prevented or minimized by controlling its production, containing it within the landfill boundary, treating it, or reversing its effects on the environment.

Several techniques which can be used to minimize leachate generation were discussed in Chapter 4:

- Ditches
- Diversions
- Benches/terraces
- Downdrains
- Drainage systems
- Sedimentation ponds
- Grading and planting
- Surface capping
- Liners.

This chapter examines eight additional technologies:

- Trenches
- Grouting
- Subsurface drainage
- Dewatering systems
- Leachate collection
- Leachate treatment
- Leachate recirculation
- Leachate attenuation.

Figure 13 presents the decision flow for choosing groundwater protection technologies.

Trenches

Slurry and clay-filled trenches are used in areas of completed landfilling where the depth of low-permeability soils is relatively low, typically less than 20 ft (Figure 14). Compacted clay or synthetic liners are typically used in new landfills, where they can be placed when the area is excavated. Slurry trenches are constructed by digging a trench into which a bentonite slurry is pumped. The slurry both stabilizes the trench walls and ultimately

forms an impermeable barrier to leachate or groundwater migration. If low-permeability clay is available on the site, trenches can also be backfilled. Clay should be compacted in lifts no more than 18-in. thick. When new areas are excavated in the landfill, a similar containment can be produced by leaving a backslope into the fill and surfacing this slope with impermeable clay.

Tables 30 and 31 present costs for two types of trenches: bentonite slurry/backfill and compacted clay; multiplier: volume of trench = 13.33 cy/ly. Both designs are 20-ft deep and 6-ft wide at the bottom.

Table 32 lists the advantages, disadvantages, and restrictions in constructing trenches for containing leachate.

If groundwater flow is not affected by the landfilling operation, or if barriers already exist (either natural or synthetic), then trenches are not needed to control lateral flow.

Grouting

Grout curtains have been used infrequently in landfills to decrease soil/rock permeability and to seal large voids. These objectives are generally achieved by one of the following methods:

1. Area grouting: low-pressure blanket or area grouting performed to seal and consolidate soils near the surface

2. High-pressure grouting: grouting at depth to seal fissures or small void spaces under high overburden

3. Contact grouting: injection of a slurry at the outer surface of an excavation to seal possible passage for water flow (a relatively complex, costly method -- as yet unproven in landfills).

Grout curtains are used primarily in areas of fractured rock and deep groundwater.

There are three types of grouting materials: cement, bituminous, and chemical. Specific grout mixtures include Portland cement, sand-cement, clay-cement, clay-bentonite, bituminous emulsions, sodium silicate, acrylamide/methylene bisacrylamide, and chrome lignin. The applicability of each material is based on grain size or fissure, and thickness of the geologic formation. A thorough subsurface investigation, including coring of fractured rock, must be done before any grouting program is designed.

Grout curtains are emplaced by forcing a thin cement grout through tubes which are driven deep into the ground on closely spaced centers (2 to 10 ft). Figures 15 and 16 depict grout curtain patterns and an upgradient application.

The equipment and techniques for installing grouting are highly specialized. A specific list of the equipment needed is not available; generally, however, specialty drills (for boring injection holes), grout mixers, and grout pumps are used. The costs in Table 33 have been developed for a typical

grout curtain, as shown in Figure 16. The curtain is 60-ft deep and consists of two rows of 2.5-ft radius pumpings. The soil was assumed to have porosity of 25 percent.

See Table 34 for a summary of the advantages, disadvantages, and restrictions in using grouting to protect groundwater.

Subsurface Drainage

Subsurface drains are mainly used to collect leachate from a site where the depth to groundwater is less than 20 ft. They are especially effective in areas of shallow perched water. Constructed of permeable rock in a trench extending into the groundwater table, subsurface drains should be at least 5 ft deeper than the lowest seasonal groundwater level. Drains are placed downgradient of the landfill to intercept contaminated groundwater leaving the landfill. If the soil profile is mainly sand, a clay or synthetic seal must be placed on the downgradient side of the drain trench. Contaminated groundwater is recovered from the drain by a pump and riser system. If the site perimeter is extensive, several pumpings will be required along the drain. A subsurface drain system is shown in Figure 17.

Table 35 gives the costs for a typical drainage system consisting of a gravel-filled trench (3-ft wide x 25-ft deep) with a perforated clay pipe in the bottom for collection. Also included is the cost of a clay trench (also 3 ft x 25 ft), which acts as a seal downgradient of the collection trench. The clay seal may not be necessary in soils with low permeability.

Table 36 lists the advantages, disadvantages, and restrictions in constructing subsurface drainage systems to control leachate.

Dewatering Systems

Extraction wells and well point systems actively collect and remove leachate at or below the level of the water table. In general, extraction wells are used for plume containment. Well point systems -- since their effect is more uniform -- are used for lowering groundwater levels. Exceptions to this generalization are outlined below.

Extraction Wells

Extraction wells may be used to collect contaminated leachate and to depress the groundwater level near or under a landfill. These wells may be developed separately or as part of an overall well-point system. In addition, when used for leachate plume control, extraction wells can be combined with injection wells to collect leachate while minimizing the overall impact of groundwater pumping on the water table level.

Groundwater pumping to lower the water table may be suitable under several conditions:

1. Lowering an unconfined aquifer so that contaminated groundwater does not discharge to a receiving stream that is hydraulically connected

2. Lowering the water table so that it is not in direct contact with the waste site

3. Lowering the water table to prevent leaky aquifers from contaminating other aquifers.

Pumping without subsequent recharge may be an acceptable approach when small quantities of groundwater are involved. However, when large groundwater flows are affected, or when residents depend on groundwater as a drinking water source, recharge will be necessary. Pumping large volumes without subsequent recharge may lead to changes in the potentiometric surface or direction of flow within a confined aquifer.

To design an effective extraction/injection well system, the FE must understand the effect of the injection wells on the drawdown and radius of influence of the extraction wells. Figure 18 shows that as the cone of depression expands and eventually encounters the cone of impression from the recharge well, both the rate of expansion of the cone and the rate of drawdown are slowed. With continued pumping, the cone of depression expands more slowly until the rate of recharge equals the rate of extraction, and the drawdown stabilizes. Thus, the injection well narrows the radius of influence and decreases the drawdown as the distance from the extraction well increases.

Because of the added pumping costs of continuously retreating water that is recontaminated by the plume, the extraction/injection well system should be designed so that the radii of influence do not overlap. Separating the radii of the wells is also important because overlaps complicate future adjustments in pumping rates. These changes might be required because of alterations in the plume caused by the age of the landfill, quantity of precipitation, and physical changes in the site, such as compaction or excavation.

Extraction wells alone can be used to contain leachate plumes (Figure 19). This system has both advantages and disadvantages when compared with the extraction/injection system. The withdrawal system does not have the added pumping and maintenance costs of an injection system, but also does not have the advantage of replenishing the groundwater supply. Use of an extraction system alone would be suited best to sites where low rates of pumping are required, or where the aquifer water supply is not needed as a drinking water source.

If groundwater recharge is necessary, seepage or recharge basins are cheaper than injection wells. Since seepage basins require extensive maintenance to ensure that porosity is not reduced, they would not be practical where several basins are needed to recharge large volumes of water, or where adequate maintenance staff is not available.

Well Point Systems

Well point systems are composed of a series of wells, usually connected by header pipes to a suction centrifugal pump. These systems may be used for both water table lowering and leachate plume containment.

As shown in Figure 20, the system consists of a group of closely spaced wells, usually connected by a header pipe and pumped by suction centrifugal

pumps, submersible pumps, or jet ejector pumps, depending on the depth of pumping and the volume to be dewatered. A pump may be connected to one well point, or a central pump may be used for the entire well point system, depending on the depth, volume, and permeability. As Figure 20 shows, the header is connected to a swing fitting that contains a valve controlling water withdrawal from each well point.

Lowering the groundwater level over the desired site involves creating a composite cone of depression by pumping from the well point system. The individual cones of depression must be close enough to overlap and thus pull the water table down several feet between pairs of wells.[4]

Cost Estimates for Dewatering Systems

Unit costs for typical items used in dewatering systems (extraction wells and wellpoint systems) are presented in Table 37. Costs vary greatly from site to site; however, typical costs would be in the range of $100,000 to $500,000 per system.

Advantages/Disadvantages

Table 38 lists advantages, disadvantages, and restrictions in using extraction wells and well point systems in dewatering to protect groundwater.

Leachate Collection

An integral part of leachate containment is the use of collection and extraction facilities to remove leachate from the landfill.

Ideally, collection systems incorporated into the design of a lined landfill can relieve hydraulic pressure on the liner. To aid leachate removal, liner materials should be sloped to drain to one or more points (preferably a grade of 1 percent or greater). Leachate is usually removed at a perimeter, internal sump coordinated with a perimeter base trench consisting of perforated drain pipe and gravel backfill. Leachate flows laterally to the drain and then into a gathering sump for treatment before it is discharged to surface streams. Figure 21 illustrates a leachate collection drain system. Costs for leachate containment (Table 39) are based on a 4-in. pipe laid in a 3-ft x 3-ft trench.

Table 40 lists advantages, disadvantages, and restrictions in collecting leachate.

Leachate Treatment

Treatment of collected landfill leachate is mandated by the CWA of 1977, which also stipulates that a permit be acquired for discharging collected leachate to surface water. Various methods of leachate treatment and discharge are available to the designers and operators of landfills: direct discharge to a sewer, or liquid waste treatment with eventual discharge to the

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[4] E. F. Johnson, Groundwater and Wells (University of Pennsylvania, 1975).

environment; recirculation in the landfill to accelerate biostabilization; spray irrigation or land application; injection of leachate into the fill; and evaporation ponds.

On-site treatment typically consists of treatment ponds with aerators (Figure 22). The coupling of anaerobic and aerobic treatment is an effective and inexpensive way to reduce the pollution characteristics of landfill leachate. If the two systems are combined in one pond, the effective area of each can be controlled with floating baffles to separate the two systems. In addition, modest to large doses of chlorine can reduce chemical oxygen demand (COD) as much as 25 to 50 percent. If more contaminants must be removed from the leachate before discharge is permitted, then filtration, or additional chemical treatment, must be provided — depending on the discharge requirements.

Because treatment systems are varied and their use is site-specific, unit costs cannot be determined. However, typical industry costs for 0.1 to 0.3 million gallons per day (mgd) facilities are listed in Table 41.

Leachate Recirculation

Recirculation essentially uses the landfill volume as an uncontrolled anaerobic digester for effective treatment of its own leachate. The recirculation of leachate increases the rate of biological stabilization of the organic fraction of the refuse, as evidenced by significant reductions in biochemical oxygen demand (BOD) and COD.

Since leachate recirculation is a specific application of leachate collection, the costs are similar to those for the collection system (see Leachate Collection). Additional costs may be incurred, however, for excavation, leachate recharge, special piping configurations, and pumping requirements.

Cost estimates for leachate recirculation can vary greatly, depending on the specific nature of the landfill site -- particularly the size of the area over which the leachate is to be circulated, and the amount of leachate.

Leachate Attenuation

As leachate percolates through soil, it reacts physically and chemically with the subsurface soil and water environment. One of the most important of these reactions is cation fixation with the clay minerals of the soil system. Negative charges concentrated on the surface of the clay particles attract cations (positive ionic species) from the leachate. The total cations that can be held on any given soil type, the cation exchange capacity (CEC), can be determined by laboratory testing. The higher the CEC, the better the ability to affix the cations in the leachate.

When landfill sites are designed and operated, the attenuation properties of the soils can be improved if the leachate flows as much as possible through surficial soils beneath the site, and if direct channels through the soil layer are eliminated. Soils that do not have sufficient attenuation capacity

naturally may be altered physically, chemically, or biologically to aid attenuation. For example, increasing soil pH is likely to increase attenuation of heavy metals.

Attenuation also can be increased by reducing the flow rate, eliminating cracks in the soil, and exposing fresh soil particle surfaces. These can be done by disturbing and compacting soil in preparing the land for waste disposal.

Leachate attenuation is a specific application of leachate collection. Therefore, attenuation costs are similar to those for a collection system (Table 39); however, additional excavation of the surface for the recharge area may be needed.

6 DISEASE

The objective of Section 4004's disease criterion is to eliminate the spread of pathogens and other disease vectors through landfilling practices. Particular emphasis is placed on the handling procedures for sewage sludge and septic tank pumpings.

Mismanaged sanitary landfills can create major health problems by providing food and shelter for common disease vectors, including rats and other rodents, domestic flies, arthropods other than flies (such as mosquitoes), birds, and stray cats and dogs. Opossums, raccoons, skunks, and bears are also attracted to garbage dumps, and because they can transmit rabies, create potential problems for humans living near the sites. The control of vectors is governed by Army Regulation (AR) 420-76 and AR 40-5.[5]

Means for preventing the transmission of disease can include:

1. Treatment of sludge and septic tank pumpings to reduce pathogens
2. Application of daily, intermediate, and final earth cover, or shredding, milling, or baling to minimize access to food and shelter
3. Use of pesticides to control rodent and insect populations
4. Drainage of stagnant water at the site to eliminate mosquito breeding grounds.

Figure 23 illustrates the series of decisions that must be made about disease control technologies.

Specific cost estimates for reducing or eliminating the potential for disease from landfills cannot be made because of the variety of possible situations. Control of disease is usually a result of proper daily operating procedures and not of elaborate construction technologies.

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5 Pest Management Programs, Army Regulation (AR) 420-76 (Headquarters [HQ], Department of the Army [DA], 15 December 1980); Health and Environment, AR 40-5 (HQ, DA, 25 September 1974).

7 AIR

The air criterion of Section 4004 controls open burning that does not conform to State Implementation Plans and the Clean Air Act.

Landfills at which a ban against open burning is strictly enforced should easily comply with this criterion if there is no other source of on-site air pollution (e.g., an incinerator) which could violate requirements of the appropriate State Implementation Plan. Careful enforcement of a policy prohibiting burning is the most effective way to meet this criterion.

At active disposal sites, some dust is usually generated during excavating and covering. This problem can be controlled by watering access roads and working areas. Blowing paper and debris can be controlled with portable litter fences placed next to active disposal areas.

Figure 24 illustrates the series of decisions that must be made about air protection techniques.

Costs for controlling the adverse impact of landfills on air quality were not derived. The wide variation in types of sites and the many alternatives for control which might exist in various regions of the country make estimates impractical since they probably would not reflect the costs to be expected at specific sites.

8 GASES

The Section 4004 safety criterion for gases is primarily concerned with preventing explosions caused by gases generated at solid waste disposal sites.

Methods for control of landfill gas are classified active or passive, depending on whether gas is forcibly withdrawn from protective features. Passive control systems are typically used where the depth to a naturally occurring gas barrier is shallow -- i.e., less than 20 ft. Natural barriers to gas include shallow groundwater or thick clay layers. When new disposal areas are constructed, gas barriers can be placed on perimeter and bottom excavation slopes, much as described in Chapter 5. When landfills have been placed in deep excavations, or when natural barriers to gas are not shallow, an active control system must be used to draw gas away from landfill perimeters. Figure 25 illustrates a possible decision flow for selecting the gas control technologies.

Liners

There are three types of impervious liners for containing gas flow: synthetic liners, admixed materials, and natural soil. These are frequently the most important features of gas control systems.

Synthetic liners are manufactured using rubber or plastic compounding. Since the integrity of impermeable membranes is critical, methods of sealing and installing the membrane are very important.

Using admixed materials such as asphaltic concrete for lining should be considered. Although not as popular for gas control as synthetic membranes, asphalts are advantageous because they are universally available, are inexpensive, and can maintain their integrity under structures. The disadvantages are relatively high permeability (as compared with synthetics), and the tendency to crack under differential settlement and weathering.

Natural soil, particularly clay, can be a highly efficient barrier to gas migration -- provided the soil is kept nearly saturated. Dry soils are relatively ineffective since cracks may develop, opening the pore space and allowing gas to pass through. Native clay soils, either in their natural state or modified by compaction, can provide an effective barrier. Alternate barrier materials, such as bentonite, may be used when on-site soils are not suitable for control.

Liner materials -- whether synthetic, admixed, or natural soil -- are best installed during landfill construction because later work is often costly, less extensive than necessary, and occasionally impossible. Figure 26 illustrates the flow of gases with liner materials in place.

Costs for liner systems have been discussed in Chapter 4.

Table 42 lists the advantages, disadvantages, and restrictions in installing liners for gas control.

Venting Systems

Venting systems may be either passive (relying on natural pressure or concentration gradients) or active (inducing exhaust by using blowers or wind vents to create a vacuum pressure gradient). The choice depends on site conditions.

Passive systems can be effective in controlling convective gas flow, but not diffusive flow. Since passive flow controls sometimes have been ineffective, the user should question the value of a passive perimeter control system; nevertheless, many have been constructed and are working. Gravel trenches, perimeter rubble vent stacks, gravel-filled vent wells, and combinations of these are examples of perimeter migration control systems. Gases from passive venting systems are usually flared (Figure 27).

Tables 43 and 44 list costs for two common passive venting systems: gravel-filled trenches and vent walls. The trench system consists of a PVC-lined gravel trench (20-ft deep x 6-ft wide at the bottom). The vent well system is a gravel-filled, 2-ft-diameter well with a perforated PVC vent pipe.

Table 45 lists advantages and restrictions in using venting systems.

Pumped Wells

Pumped wells are induced or active flow systems that are very effective in migration control -- particularly those with suitably designed vertical wells.

In practice, systems combining both migration control and gas recovery seem to be preferred. These systems usually incorporate perforated pipe in grouped, vertical, gravel-filled wells similar to those used in gas recovery systems. The wells are spaced at regular intervals near the perimeter of the landfill, and, depending on system requirements, are either inside the fill's boundary, or outside in the surrounding natural soils. The wells are connected by manifolds to a central exhaust pump which draws gas from the well field. The gas flow within the landfill is directed toward each of the wells, thereby effectively controlling migration. The collection pipe also can be placed in a gravel-filled trench and then connected to a vacuum exhaust system to improve the trench system's control of gas. Gases collected by pumped well systems are generally disposed of by direct stacking, incineration, or passage through various absorption media (Figure 28).

Pumped wells use the designs presented in Venting Systems. Table 46 lists additional costs for pumped systems.

Table 47 lists restrictions in using pumped systems.

Monitoring

The perimeter soil of a site may be sampled by probes at the property boundary. The simplest method of monitoring gas composition in soils and refuse is with a bar-hole probe (Figure 29). This is simply a rigid, hollow

tube which is attached by flexible tubing to the inlet of a gas detection device. The probe is inserted into the bar hole, and the hole is sealed around the probe at the surface, typically with rubber stopper, cloth, or native soil. A gas sample is then drawn from the probe through the gas detection instrument, which indicates the gas composition in the bar-hole.

A bar-hole may detect methane and indicate the presence of combustible gas. However, a failure to detect methane does not necessarily indicate the absence of combustible gas. Usually gas is sampled immediately after a probe is in place. However, it may take days for migrating gas to accumulate to a representative level. In many investigations, shallow bar-hole probe surveys have failed to detect significant methane concentrations, but subsequent monitoring with deeper permanent probes has shown the gas to be present at relatively high levels. In addition, the results of a bar-hole probe survey cannot be reproduced since a new hole must be made each time a survey is conducted. Therefore, permanent gas monitoring probes with periodic monitoring are preferable to bar-hole probe surveys for checking the presence or characteristics of landfill gas in soils or refuse.

Various soil samples, test wells, and analyses are available for site monitoring. The selection of the type and number of samples depends on the specific nature of the site. Unit costs are given in Table 48 for various activities involved in monitoring.

9 FIRE HAZARDS

The Section 4004 safety criterion for fires is intended to eliminate hazards to property and health. This can be done most effectively with a rigid ban against open burning, and a program to minimize the risk of accidental underground and aboveground fires.

Since organic material left exposed to free oxygen can ignite by spontaneous combustion, such wastes must be covered each day to limit the quantity of free oxygen available. Soil cover decreases the likelihood of combustion, and if a fire does develop, it is isolated to the cell in which it starts. Compaction, which decreases available air space in the fill, is also recommended — particularly to control underground fires.

Simple, common-sense site operation practices are effective in controlling landfill fires. Equipment operators should always carry fire extinguishers to put out small blazes. If a fire is too large, waste in the burning area should be spread out so that water can be applied. This can be an extremely hazardous chore; to protect the operator and equipment, water should be sprayed on the parts of the machine that come in contact with hot wastes. Obviously, a hauler arriving at a landfill with a burning or hot load should be sent to a separate area of the landfill, away from the working face, where the fire can be put out before landfilling. Moreover, each landfill should have a fire-fighting plan with which all site personnel are thoroughly familiar.

Figure 30 illustrates the series of decisions that must be made about fire control technologies.

No cost estimates could be derived for fire control. Equipment needs and daily operating practices are too varied to allow analysis of specific costs.

10 BIRD HAZARDS

The Section 4004 safety criterion for bird hazards is intended to control problems associated with bird populations near solid waste disposal facilities accepting putrescible wastes. For example, birds at landfills close to airports may be a hazard to aircraft.

Of the several techniques for controlling birds, the most effective is limiting the availability of food and shelter at the landfill. This can be done by (1) locating landfills in areas less likely to attract birds, and (2) periodically applying cover material during landfill operation. Whenever possible, landfills should be far from the flight paths of birds and aircraft.

Two devices also may be useful: "teleshot," a shotgun shell loaded with a secondary aerial detonation charge, and wire "cable canopy," a grid of thin wires suspended over the active fill area. Unit costs for a cable canopy are given in Table 49.

Figure 31 illustrates the series of decisions that must be made about controlling bird hazards.

11 ACCESS

The Section 4004 safety criterion for access is intended to keep unauthorized personnel from entering a landfill.

Fencing is the most common means of controlling or limiting access to a disposal site. Permanent or portable woven and chain link fencing, or combinations of both, are commonly used. A gate at the site's entrance should be closed when the landfill is not open. In addition, earth berms, ditches, and natural features such as hills, slopes, water, or wooded areas may help limit access or serve as visual screens.

Figure 32 illustrates the series of decisions that must be made about controlling access.

Table 50 gives the costs for a 6-ft-high chain link industrial fence surrounding a site 200 ft x 200 ft. These costs include 30-ft gates, and braces on every other line post (36 total).

12 CLOSURE

If upgrading would be either too expensive or technically prohibitive, the open dump must be closed. To comply with the RCRA guidelines, closure must minimize further environmental contamination from the unused landfill. The methods and long-term requirements for open dump closure include the remedial techniques discussed in the preceding chapters:

1. Monitoring
   -- groundwater
   -- gas
2. Capping
3. Regrading
4. Revegetation
5. Access
6. Leachate collection
7. Gas control
   -- venting
   -- wells

The use of these closure techniques depends on geologic conditions, solid waste type, waste disposal practices, and the features at the landfill which caused it to be classified an open dump. For instance, if the landfill violated the RCRA criteria for gas migration, then the proper practice for closure should be a combination of gas venting and monitoring. In selecting landfill closure techniques, the FE must remember that the contamination caused by the dump must be prevented after closure.

Monitoring

If a landfill is closed because of groundwater contamination or gas migration, the site must be monitored to prove that closure techniques are preventing further contamination from either of these sources.

Groundwater Monitoring

Groundwater monitoring is done by installing groundwater monitoring wells, which are typically 4 in. in diameter and PVC-cased. The prices and techniques of well installation vary greatly from one geographic location to another. A figure of $40/ft is used for a rough calculation of well installation costs. The actual constituents that will be monitored in the groundwater vary according to State regulations, solid waste type, and the National Interim Drinking Water Standards.

Gas Monitoring Wells

Gas monitoring wells are discussed in Chapter 8.

Capping

Capping is used to close open dumps so that water does not percolate through the site and contribute to groundwater and surface water

contamination. Capping also prevents the contamination of surface runoff at a disposal site. An incidental benefit of surface capping is that it limits access, and therefore vandalism, at the landfill site. Surface capping is discussed in more detail in Chapter 4.

Regrading

Regrading is generally done at all sites that have to be closed. Regrading secures the perimeter and top of the landfill, leaving no open pits for further disposal of waste material. Proper regrading helps prevent erosion at the dump. Regrading is discussed in Chapter 4.

Revegetation

Revegetation should also be done before closing. In addition to making the open dump site more attractive, revegetation prevents erosion and surface runoff. This technique is discussed in Chapter 4.

Access

Depending on State regulations and the future use of the closed landfill, access can be controlled in several ways. At a restricted military base, access can be controlled by posting and intermittent patrol, or the site can be continuously patrolled. The most common method of limiting access is to fence the entire site, with the only entrance a locked gate. Access is discussed in Chapter 11.

Leachate Collection and Treatment

If the landfill is being closed because it is producing contaminated leachate, the effluent must be collected or its generation after closure prevented.

If the collected leachate must be treated, there are several options:

1. Activated sludge treatment
2. Ammonia stripping
3. Anaerobic lagoons
4. Biological seeding
5. Carbon absorption
6. Chlorination
7. Equalization
8. Ion exchange
9. Leachate recirculation
10. Leachate attenuation.

Leachate collection and treatment are discussed in Chapter 5.

Gas Control

Gas is controlled by venting or monitoring with gas wells and testing. Improper venting of gas generated at a landfill can be the most hazardous effect of solid waste disposal. Gas control is discussed in Chapter 8.

13 CONCLUSION

The FE may use several technologies to upgrade or close a landfill to comply with RCRA Section 4004 criteria. This report has described each alternative, discussed its advantages, and given costs that the FE can use to make order-of-magnitude estimates and to compare specific alternatives for upgrade.

Table 1

Compliance Alternatives

RCRA Criteria Category	Reason for Noncompliance	Levee (14)	Flood Wall (14)	Dredging (14)	Washout Prevention (15)	Selective Landfilling (16)	Mitigation Land (16)	Deep or Vertical Landfilling (16)	Ditches (17)	Diversions (18)	Benches/Terraces (18)	Chutes and Downdrains (19)	Drainage Systems (19)	Sedimentation Ponds (20)	Grading and Planting (21, 40)	Surface Capping (21, 39)	Liners (22, 33)	Seep Control (22)	Trenches (24)	Grouting (25)	Subsurface Drainage (26)	Extraction Wells (26)	Leachate Collection (28, 40)	Leachate Treatment (28, 40)	Leachate Recirculation (29)	Leachate Attenuation (29)	Disease Control (31)	Compliance with Clean Air Criteria (32)	Venting Systems (34, 41)	Pumped Wells (34, 41)	Monitoring (34, 39)	Reduction of Fire Hazards (36)	Daily Cover (36)	"Teleshot" (37)	Cable Canopy (37)	Fencing (38, 40)	Groundwater Monitoring (39)
Floodplains	Restricts flow at a flood	X	X	X																																	
	No washout protection				X																																
Endangered species	Adverse to critical habitat or endangered species					X	X	X																													
Surface water	Point source discharge								X	X	X	X	X	X	X	X	X	X																			
	Nonpoint source discharge								X	X	X	X	X	X	X	X	X																				
Groundwater	Contaminates drinking water supply								X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X											
Disease	Disease vectors not minimized																										X										
Air	Unapproved open burning																											X									
Safety	Methane concentration too high																												X	X	X						
	Fire hazard																															X					
	Bird hazard																																X	X	X		
	Uncontrolled access																																			X	
	Closure												X	X									X	X													X

*Parenthetical numbers are pages on which technologies are discussed.

Table 2

Costs for Levees

Multipliers: Volume of levee = 31.9 cubic yard/linear yard (cy/ly)
Surface area of forward slope = 13.34 square yard/linear yard (sy/ly)
Volume of 1-ft strip = 6.3 cy/ly

	Activity		Unit Cost	Multiplier		Cost/ly
1.	Excavation of 1' strip under levee	L**	1.13	6.3 cy/ly	=	7.12
		E	0.70		=	4.41
	A. Crew (B10L)*	M	-		=	-
		T	$1.83/cy		=	$11.50/ly
	Daily output = 200 cy/day					
	B. Crew (B33B)	L	0.67	6.3 cy/ly	=	4.22
		E	2.24		=	14.10
		M	-		=	-
		T	$2.91/cy		=	$18.40/ly
	Daily output = 500 cy/day					
2.	Borrow excavation native clay fill	L	0.81	31.9 cy/ly	=	25.80
		E	1.45		=	46.30
	Crew (B15)	M	1.00-4.00		=	31.90-127.60
		T	$3.30-6.30/cy		=	$104-200/ly
	Daily output = 600 cy/day					
3.	Grading at site	L	0.41	31.9 cy/ly	=	13.10
	Crew (B10M)	E	1.13		=	36.00
		M	-		=	-
		T	$1.54/cy		=	$49.10/ly
	Daily output = 560 cy/day					
4.	Compaction	L	0.63	31.9 cy/ly	=	20.10
	Crew (B10G)	E	0.66		=	21.10
		M	-		=	-
		T	$1.29/cy		=	$41.10/ly
	Daily output = 360 cy/day					

*Crew code descriptions are given in Appendix B.
**L-labor; E-equipment; M-materials; T-total.

Table 2 (Cont'd)

Activity		Unit Cost	Multiplier		Cost/ly
5. Erosion control options	L	0.13	13.34 sy/ly	=	1.73
A. Mulching and seeding	E	0.03		=	0.40
Crew (A1)	M	0.33		=	4.40
	T	$0.49/sy		=	$6.50/ly
Daily output = N/A					
B. Rip-rap slope	L	4.97	4.45-	=	22.10-44.20
protection 1-2' deep	E	4.00	8.89 cy/ly	=	17.80-35.60
Crew (B12G)	M	7.70		=	34.20-68.40
	T	$16.70/cy		=	$74 - 148/ly
Daily output = 62 cy/day					

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Levee construction	$63-66/ly	$108-118/ly	$32-128/ly	$203-312/ly
w/seeding	$65-68/ly	$108-118/ly	$36-132/ly	$209-318/ly
w/rip-rap	$87-112/ly	$126-154/ly	$70-200/ly	$283-466/ly

Table 3

Floodwall Costs

Activity		Unit Cost	Multiplier		Cost/ly
1. Gravity concrete wall	L	75.99	3 lf/ly*	=	228
Crew (C14)	E	22.89		=	69
	M	92.40		=	277
	T	$191/lf		=	$574/ly
Daily output = 40 lf/day					

*lf = linear foot.

Table 3 (Cont'd)

Activity		Unit Cost	Multiplier		Cost/ly
2. Reinforced	L	65.37	3 lf/ly	=	196
concrete cantilever	E	19.70		=	59
Crew (C14)	M	63.80		=	191
	T	$149/lf		=	$447/ly

Daily output = 43 lf/day

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Floodwall construction	$196-228/ly	$59-69/ly	$191-277/ly	$447-574/ly

Table 4

Costs for Control of Backwater Flow

Activity	Unit Cost
Barge mounted clamshell excavation into scows, dumped	$5.50-8.00/cy
Barge mounted clamshell or dragline, hopper dumped, pumped 1000'	$4.50-6.50/cy
Hydraulic dredge pumped 1000'	$3.00-5.00/cy
Dragline	$1.39-2.00/cy
Shovel	$1.10-2.34/cy
Dredging mobilization and demobilization costs	$5000-25,000 ea.

Table 5

Advantages, Disadvantages, and Restrictions in Using Diversion Systems in Floodplains

Function	Advantages	Disadvantages	Restrictions
Barrier preventing flow of flood-waters onto landfill.	Standard construction techniques & equipment used. Required earthfill may be available on site.	Periodic inspections and maintenance to ensure structural integrity and prevent upslope deposition of sediments. Improperly installed they may cause soil instability and leachate generation. Must be rebuilt, regraded and/or revegetated in the event of flooding.	Most effective when combined with grading and revegetation. Requires suitable capping and cover materials.

Table 6

Costs of Washout Prevention

Activity		Cost/sy
Gabion placement, 6" deep galvanized steel mesh boxes, stone filled	L	5.04
	E	1.87
	M	8.47
Crew (B13)		
	T	\$15.40/sy

Daily output = 190 sy/day

Table 7

Advantages, Disadvantages, and Restrictions in Using Washout Prevention Techniques in Floodplains

Functions	Advantages	Disadvantages	Restrictions
Prevents surface materials from washing out during flood events.	Low maintenance.	Does not prevent floodwater intrusion.	May be used with infiltration barriers.

Table 8

Costs for Ditches

Activity		Unit Cost	Multiplier		Cost/ly
1. Trench excavation	L	1.45-1.93	1.78 cy/ly	=	2.58-3.44
Crew (B11C)	E	0.85-0.89		=	1.51-1.58
or (B11M)	M	-		=	-
	T	$2.30-2.82/cy		=	$4.09-5.02/ly
Daily output = 150-200 cy/day					
2. Grading at site (smooth ditch, grade support ridge)	L	0.41-1.42	1.78 cy/ly	=	0.73-2.53
	E	1.13-0.87		=	2.01-1.55
	M	-		=	-
Crew (B10L) or (B10M)	T	$1.54-2.29/cy		=	$2.74-4.08/ly
Daily output = 160-560 cy/day					
3. Compaction	L	0.41	1.78 cy/ly	=	0.73
Crew (B10C)	E	0.89		=	1.58
	M	-		=	-
	T	$1.30/cy		=	$2.31/ly
Daily output = 550 cy/day					

Table 8 (Cont'd)

	Activity		Unit Cost	Multiplier		Cost/ly
4.	Erosion control options	L	0.13	4.31 sy/ly	=	0.56
		E	0.03		=	0.13
	A. Mulching and seeding	M	0.33		=	1.42
	Crew (A1)	T	$0.49/sy		=	$2.11/ly
	Daily output = N/A*					
	B. Stone rip-rap (stabilization) center 0.5-1' deep, 1' wide	L	4.97	0.056-	=	0.28-0.55
		E	4.00	0.111 cy/ly	=	0.22-0.44
		M	7.70		=	0.43-0.85
	Crew (B12G)	T	$16.67/cy		=	$0.93-1.84/ly
	Daily output = 62 cy/day					

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Ditch construction	$4.40-7.10/ly	$4.20-4.80/ly	-	$ 9.10-11.40/ly
w/seeding	$5.00-7.70/ly	$4.40-4.90/ly	$1.40/ly	$11.20-13.50/ly
w/seeding and rip-rap	$5.30-8.20/ly	$4.60-5.30/ly	$0.40-0.90/ly	$12.20-15.30/ly

*Not applicable.

Table 9

Advantages, Disadvantages, and Restrictions in Using Ditches in Protecting Surface Water

Function	Advantages	Disadvantages	Restrictions
Upslope perimeter, channel runoff around critical areas; downslope & on-site, control transports of contaminated runoff.	Standard construction techniques, equipment used. Required fill material readily available.	Periodic inspections and maintenance required.	For channel slopes, 5% stabilization with grasses, mulches, sod, or stone rip-rap necessary.

Table 10

Advantages, Disadvantages, and Restrictions in Using Diversions for Runoff Control

Function	Advantages	Disadvantages	Restrictions
Provide more permanent erosion control on long slopes subject to heavy flow.	Standard construction techniques, equipment used. Required fill material readily available.	Periodic inspections and maintenance required.	Recommended for use on slopes of 15% or less.

Table 11

Permissible Design Velocities for Stabilized Diversions (From Erosion and Sediment Control: Surface Mining in the Eastern United States, EPA Technology Transfer [U.S. Environmental Protection Agency (EPA), 1976]

Cover	Channel Grade (%)	Maximum Design Velocity (ft/sec)
Vegetative		
• Bermuda grass	0-5	6
	5-10	5
	10	4
• Reed canary grass, tall fescue, Kentucky bluegrass	0-5	5
	5-10	4
	10	3
• Grass-legume mix	0-5	2.5
	5-10	3
• Red fescue, Redtop, Sericea lespedeza	0-5	2.5
• Annuals, small grain (rye, oats, barley), Ryegrass	0-5	2.5
Mechanical and Vegetative		
Stone center	All	As determined from vegetative cover above.

Table 12

Costs for Benches/Terraces

Activity		Unit Cost	Multiplier		Cost/ly
1. Borrow excavation	L	0.81	0.75 cy/ly	=	0.61
Common borrow	E	1.45		=	1.09
Crew (B15)	M	1.10		=	0.83
	T	$3.36/cy		=	$2.52/ly
Daily output = 600 cy/day					
2. Compaction: 1-ton	L	1.81	0.75 cy/ly	=	1.36
handroller compaction	E	0.47		=	0.35
Crew (B10A)	M	-		=	-
	T	$2.28/cy		=	$1.71/ly
Daily output = 125 cy/day					
3. Erosion control	L	0.13	2.24 sy/ly	=	0.29
options	E	0.03		=	0.07
A. Mulching and seeding	M	0.33		=	0.74
Crew (A1)	T	$0.49/sy		=	$1.10/ly
Daily output = N/A					
B. Bituminous concrete	L	1.80	2.24 sy/ly	=	4.03
Barn mix, 3" layer	E	0.13		=	0.29
Crew (B37)	M*	-		=	6.80
	T	-		=	$11.10/ly
Daily output = 450 sy/day					
C. Rip-rap control,	L	11.98	2.24 sy/ly	=	26.84
3/8-1/4 cy	E	4.44		=	9.95
pieces, grouted	M	6.05		=	13.55
Crew (B13)	T	$22.47/sy		=	$50.30/ly
Daily output = 80 sy/day					

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Bench construction	$ 2.00/ly	$ 1.40/ly	$ 0.80/ly	$ 4.20/ly
w/seeding	$ 2.30/ly	$ 1.50/ly	$ 1.60/ly	$ 5.30/ly
w/bituminous	$ 6.00/ly	$ 1.70/ly	$ 7.60/ly	$15.30/ly
w/rip-rap	$28.80/ly	$11.40/ly	$14.40/ly	$54.50/ly

*Based on 145 lb/cf and $18.70/ton for bituminous concrete.

Table 13

Advantages, Disadvantages, and Restrictions in Constructing Benches/Terraces

Function	Advantages	Disadvantages	Restrictions
Reduce slope to decrease rate of flow of runoff to nonerosive rates.	Easily incorporated into final grading schemes. Standard equipment and materials.	If improperly designed, excessive maintenance costs. Periodic inspections required especially after rain.	Width and spacing depend on slope steepness, soil type, and slope length. Work most effectively in areas of high precipitation. Must be used with vegetation.

Table 14

Costs for Paved Chutes

Multipliers: Volume of chute = 1.28 cy/ly
Surface area of chute = 4.53 sy/ly
Volume of rip-rap bed = 8 cy minimum

	Activity		Unit Cost	Multiplier		Cost/ly
1.	Excavation of chute	L	0.28-1.13	1.28 cy/ly	=	0.36-1.45
	Crew (B10L)	E	0.78-0.70		=	1.00-0.86
	or (B10M)	M	-		=	-
		T	$1.06-1.83/cy		=	$1.36-2.30/ly
	Daily output = 200-800 cy/day					
2.	Compaction of chute	L	0.41	1.28 cy/ly	=	0.52
	Crew (B10C)	E	0.89		=	1.14
		M	-		=	-
		T	$1.30/cy		=	$1.66/ly
	Daily output = 550 cy/day					

Table 14 (Cont'd)

	Activity		Unit Cost	Multiplier		Cost/ly
3.	Paving	L	$0.82-1.80/sy	4.53 sy/ly	=	3.71-8.15
	A. Bituminous concrete,	E	0.33-0.13		=	1.49-0.59
	3" layer-berm mix	M**	-		=	13.80
	Crew (B25)					
	or (B37)*	T	-		=	$19.00-22.50/ly
	Daily output = 450 sy/day					
	B. Concrete paving,	L	0.52/sy	4.53 sy/ly	=	2.35
	4" thick, redimix	E	0.37/sy		=	1.68
	4500 psi	M	46/cy		=	23.00
	Crew (B26)					
		T	-		=	$27.00/ly
	Daily output = N/A					
4.	Rip-rap stabilization bed, minimum size	L	1.13	8 cy (min)	=	9.04
		E	0.70		=	5.60
	A. Excavation	M	-		=	-
	Crew (B10L)					
		T	$1.83/cy		=	$14.60 ea (min)
	Daily output = 200 cy/day					
	B. Borrow excavation	L	0.81	8 cy (min)	=	6.48
	- filterstone	E	1.45		=	11.60
	Crew (B15)	M	7.70		=	61.60
		T	$9.96/cy		=	$79.70 ea (min)
	Daily output = 600 cy/day					

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Chute construction	$0.90-2.00/ly	$2.00-2.10/ly	-	$3.00-4.00/ly
w/lining	$3.20-10.10/ly	$2.60-3.80/ly	$13.80-23.00/ly	$22-31/ly
Rip-rap bed	$1.90/cy	$2.15/cy	$7.70/cy	$11.80/cy

*It may not be possible or practical to use a paving machine and roller for many situations.

**Costs based on 145 lb/cf and $18.70/ton for bituminous.

Table 15

Costs for Downpipes

Multipliers: Volume of excavation = 0.25-1.00 cy/ly
Volume of rip-rap apron = 6 cy minimum

	Activity		Unit Cost	Multiplier		Cost/ly
1.	Excavation	L	1.13	0.25-1.00 cy/ly	=	0.28-1.13
	Crew (B10L)	E	0.70		=	0.18-0.70
		M	-		=	-
		T	$1.83/cy		=	$0.46-1.83/ly
	Daily output = 200 cy/day					
2.	Compaction-vibratory plate	L	1.67	0.25-1.00 cy/ly	=	0.42-1.67
	Crew (A1)	E	0.44		=	0.11-0.44
		M	-			-
		T	$2.11/cy		=	$0.53-2.11/ly
	Daily output = 75 cy/day					
3.	Piping-corrugated galvanized metal,	L	7.37	3 lf/ly	=	22.10
	36" diam., 12 ga.	E	2.73		=	8.20
	Crew (B13)	M	17.60		=	52.80
		T	$27.70/lf		=	$83/ly
	Daily output = 130 lf/day					
4.	Rip-rap apron	L	1.13	6 cy (min)	=	6.78
	A. Excavation	E	0.70		=	4.20
	Crew (B10L)	M	-		=	-
		T	$1.83/cy		=	$11.00 ea (min)
	Daily output = 200 cy/day					
	B. Borrow excavation	L	0.81	6 cy (min)	=	4.86
	filter stone	E	1.45		=	8.70
	Crew (B15)	M	7.70		=	46.20
		T	$9.96/cy		=	$59.80 ea (min)
	Daily output = 600 cy/day					

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Downpipe construction	$22.80-24.90/ly	$8.50-9.30/ly	$52.80/ly	$84-87/ly
Rip-rap bed	$ 1.90/cy	$2.20/cy	$7.70/cy	$11.80/cy

Table 16

Advantages, Disadvantages, and Restrictions in Using Chutes and Downdrains to Control Surface Runoff

Function	Advantages	Disadvantages	Restrictions
Temporarily constructed to carry concentrated flows of surface runoff from one level to a lower level without erosive damage.	Inexpensive and quick construction methods; suitable for emergency measure. Standard materials and equipment. Effective for long, steep slopes. Can be key in combined surface control systems.	Periodic inspections necessary. Additional costs for removal. May overflow and cause severe erosion if improperly designed.	Suitable in small areas (>5 acres).

Table 17

Costs for Gravel-Filled Trenches

Multipliers: Volume of gravel fill = 2.67 cy/ly
Volume of topsoil fill = 0.67 cy/ly
Surface area of gravel = 7.33 sy/ly

	Activity		Unit Cost	Multiplier		Cost/ly
1.	Trench excavation	L	0.77	3.33 cy/ly	=	2.56
	Crew (B12A)	E	0.83		=	2.76
		M	-		=	-
		T	$1.60/cy		-	$5.30/ly

Daily output = 400 cy/day

Table 17 (Cont'd)

	Activity		Unit Cost	Multiplier		Cost/ly
2.	Fabric installation*	L**	0.50	7.33 sy/ly	=	3.67
		E	-		=	-
		M**	1.00		=	7.33
		T	$1.50/sy		=	$11.00/ly
	Daily output = N/A					
3.	Borrow excavation, 3/4" crushed stone fill Crew (B15)	L	0.81	2.67 cy/ly	=	2.16
		E	1.45		=	3.87
		M	6.05		=	16.15
		T	$8.31/cy		=	$22.20/ly
	Daily output = 600 cy/day					
4.	Dozer backfilling Crew (B10B)	L	0.27	0.67 cy/ly	=	0.18
		E	0.52		=	0.35
		M	-		=	-
		T	$0.79/cy		=	$0.53/ly
	Daily output = 825 cy/day					
5.	Grading of excavated earth Crew (B10M)	L	0.41	2.67 cy/ly	=	1.09
		E	1.13		=	3.02
		M	-		=	-
		T	$1.54/cy		=	$4.10/ly
	Daily output = 560 cy/day					

TOTAL COST:

	Labor	Equipment	Materials	Total
Trench construction	$9.70/ly	$10.00/ly	$27.20/ly	$47/ly

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*Manual for Remedial Actions at Solid Waste Disposal Sites (JRB Associates, 1980.

**Assumed labor and material cost distribution.

Table 18

Costs for PVC Piping/Trench Systems

Multipliers: Volume of gravel fill = 0.83 cy/ly
Volume of topsoil fill = 0.17 cy/ly

	Activity		Unit Cost	Multiplier		Cost/ly
1.	Trench excavation	L	1.21	1.00 cy/ly	=	1.21
	Crew (B12Q)	E	0.90		=	0.90
		M	-		=	-
		T	$2.11/cy		=	$2.10/ly
	Daily output = 250 cy/day					
2.	Borrow excavation,	L	0.81	0.83 cy/ly	=	0.67
	3/4" crushed	E	1.45		=	1.20
	stone fill	M	6.05		=	5.02
	Crew (B15)					
		T	$8.31/cy		=	$6.89/ly
	Daily output = 600 cy/day					
3.	PVC Pipe installation, 4" perforated,	L	2.53	3 lf/ly	=	7.59
		E	-		=	-
	class 160	M	1.54		=	4.62
	Crew (B20)					
		T	$4.07/lf		=	$12.20/ly
	Daily output = 200 lf/day					
4.	Grading of	L	0.41	1.00 cy/ly	=	0.41
	excavated earth	E	1.13		=	1.13
	Crew (B10M)	M	-		=	-
		T	$1.54/cy		=	$1.54/ly
	Daily output = 560 cy/day					

TOTAL COST:

	Labor	Equipment	Materials	Total
Construction	$9.90/ly	$3.20/ly	$9.60/ly	$22.70/ly

Table 19

Advantages, Disadvantages, and Restrictions in Using Drainage Systems for Controlling Runoff and Leachate Seepage

Function	Advantages	Disadvantages	Restrictions
Collect contaminated runoff & groundwater for disposal and/or to control leachate.	Cost-effective means of intercepting runoff. Reliable performance with maintenance.	Susceptible to clogging. Not effective in poorly permeable soils.	Low soil permeability will inhibit drainage.

Table 20

Costs for Sedimentation Ponds and Basins

Multipliers: 1613.3 cy/acre-ft (a-ft)

Activity		Unit Cost	Multiplier		Cost/ly
1. Bulk excavation	L	0.19	1613.3 cy/a-ft	=	307
A. Crew (B10M)	E	0.53		=	855
	M	-		=	-
	T	$ .72/cy		=	$1160/a-ft
Daily output = 1200 cy/day					
B. Crew (B12G)	L	1.93	1613.3 cy/a-ft	=	3110
	E	1.55		=	2500
	M	-		=	-
	T	$3.48/cy		=	$5610/a-ft
Daily output = 1600 cy/day					
2. Grading	L	0.41	1613.3 cy/a-ft	=	660
Crew (B10M)	E	1.13		=	1820
	M	-		=	-
	T	$1.54/cy		=	$2480/a-ft
Daily output = 5600 cy/day					

Table 20 (Cont'd)

Activity		Unit Cost	Multiplier		Cost/ly
3. Compaction Crew (B10G)	L	0.63	1613.3 cy/a-ft	=	1020
	E	0.66		=	1060
	M	-		=	-
	T	$1.29/cy		=	$2080/a-ft

Daily output = 360 cy/day

4. Additional costs

A. Paved spillway construction, installed $20-30/sy*

B. Rip-rap impact control Crew (B12G)	L	4.97
	E	4.00
	M	7.70
	T	$16.70/cy

Daily output = 600 cy/day

C. Mulching and seeding Crew (A1)	L	0.13
	E	0.03
	M	0.33
	T	$0.49/sy

Daily output = N/A

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Pond construction	$1990-4790/a-ft	$3740-5380/a-ft	-	$5720-10,200/a-ft
Additional costs				
Spillway				$20-30/sy
Rip-rap	$4.97/cy	$4.00/cy	$7.70/cy	$16.70/cy
Seeding	$0.13/sy	$0.03/sy	$0.33/sy	$ 0.49/sy

*Manual for Remedial Actions at Waste Disposal Sites (JRB Associates, 1980).

Table 21

Advantages, Disadvantages, and Restrictions in Using Sedimentation Ponds

Function	Advantages	Disadvantages	Restrictions
Collect contaminated sediments and keep them from surface runoff.	Easy to design and install. Requires low operational & maintenance effort. Very effective removal of suspended solids.	Cannot be used to remove other contaminants, such as inorganic & organic chemicals. Faulty design of embankment may cause damage.	For large drainage areas, large land requirements.

Table 22

Costs for Regrading and Revegetation

Activity	Unit Cost
1. Grading Crew (B10M) or (B10L)	L = 0.41-1.42 E = 1.13-0.87 M = - T = $1.54-2.29/cy
Daily output = 160-560 cy/day	
2. Compaction Crew (B10G)	L = 0.63 E = 0.66 M = - T = $1.29/cy
Daily output = 360 cy/day	
3. Borrow excavation, common fill Crew (B15)	L = 0.81 E = 1.45 M = 1.10 T = $3.36/cy
Daily output = 600 cy/day	
4. Mulching and seeding	L = 0.13 E = 0.03 M = 0.33 T = $0.49/sy
Daily output = N/A	

Table 23

Advantages, Disadvantages, and Restrictions In Grading and Planting to Enhance Surface Runoff

Function	Advantages	Disadvantages	Restrictions
Enhances runoff while minimizing erosion; stabilizes surface.	May be economical if materials readily available.	Regular maintenance required. Materials may not be readily available (high hauling costs may result).	May require irrigation in arid climates.

Table 24

Approximate Seasonal Consumption of Water*

Growth	Inches	Growth	Inches
Coniferous Trees	4-9	Alfalfa and Clover	2.5 up
Deciduous Trees	7-10	Oats	28-40
Rye	18 up	Meadow Grass	22-60
Wheat	20-22	Lucern Grass	26-65

*G. L. Gerdes and B. A. Donahue, Simplified Sanitary Landfill Design and Operation Analysis, Technical Report N-57/ADA064356 (CERL, 1978), p. 36, as taken from J. Reindl, "Landfill Course," Solid Wastes Management, Vol. 20, No. 7 (1977), p 31.

Table 25

Costs of Surface Capping

Multiplies: Volume of 4' thick fill = 1.33 cy/sy

	Activity		Unit Cost	Multiplier		Cost/sy
1.	Borrow excavation, 4' of common fill or clay Crew (B15)	L	0.81	1.33 cy/sy	=	1.08
		E	1.45		=	1.93
		M	1.00-4.00		=	1.33-5.32
		T	$3.30-6.30/cy		=	$4.34-8.33/sy
	Daily output = 600 cy/day					
2.	Compaction Crew (B10G)	L	0.63	1.33 cy/sy	=	0.84
		E	0.66		=	0.88
		M	-		=	-
		T	$1.29/cy		=	$1.72/sy
	Daily output = 360 cy/day					
3.	Capping materials					
	A. PVC membrane, 20 mil*	L**	0.30-0.50			
		E				
		M**	1.00-1.50			
		T	$1.30-2.00/sy			
	Daily output = N/A					
	B. Bentonite cement, 4-6" thick Crew (B10C)	L	0.41	0.11-0.17 cy/sy	=	0.50-0.07
		E	0.89		=	0.10-0.15
		M***	179-211		=	19.70-35.90
		T	$180-212/dy		=	$19.80-36.00/sy
	Daily output = 550 cy/day					
	C. Bituminous concrete berm mix, 3" thick Crew (B37)	L	1.80			
		E	0.13			
		M	1.35-2.10			
		T	$3.30-4.00/sy			
	Daily output = 450 sy/day					

*Manual for Remedial Actions at Waste Disposal Sites (JRB Associates, 1980).
**Assumed labor and material cost distribution.
***Based on 156 lb/cf and $85-100/ton for bentonite.

Table 25 (Cont'd)

Activity		Unit Cost	Multiplier	Cost/sy
4. Mulching and seeding Crew (A1)	L	0.13		
	E	0.03		
	M	0.33		
	T	$0.49/sy		

Daily output = N/A

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Clay	$2.10/sy	$2.80/sy	$ 1.70-5.70/sy	$ 6.60-10.50/sy
PVC	$2.40-2.60/sy	$2.90/sy	$ 2.70-3.20/sy	$ 7.90- 8.60/sy
Bentonite	$2.10/sy	$2.90-3.00/sy	$21.40-37.60/sy	$26.40-42.60/sy
Bituminous concrete	$3.90/sy	$3.00/sy	$ 3.00-3.80/sy	$ 9.90-10.60/sy

Table 26

Advantages, Disadvantages, and Restrictions in Using Synthetic and Clay Capping Materials

Material	Advantages	Disadvantages	Restrictions
Clay or high clay content soil	Economically preferable in areas where clay is available.	Fine-grained clays may dry and crack during dry seasons. Maintenance required to keep clay moist and to prevent plants with deep systems from penetrating cap.	Must be combined with grading and planting to be effective.
Synthetic materials	When clay is not available (or transportation costs are excessive), may be economically preferable.	Routine maintenance necessary as described above. Easily punctured. Relatively expensive.	Grading and planting must accompany.

Table 27

Costs for Liners

Multipliers: Volume of earth excavated = 0.67 cy/sy
= 3226.6 cy/acre

Activity	Unit Cost	Multiplier		Cost/Acre
1. Bulk excavation A. Crew (B10M)	L 0.19	3226.6 cy/a	=	613
	E 0.53		=	1710
	M -		=	-
	T $0.72/cy		=	$2320/a
Daily output = 1200 cy/day				
B. Crew (B12G)	L 1.93	3226.6 cy/a	=	6230
	E 1.55		=	5000
	M -		=	-
	T $3.48/cy		=	$11,200/a
Daily output = 160 cy/day				
2. Grading Crew (B10M)	L 0.41	3226.6 cy/a	=	1320
	E 1.13		=	3650
	M -		=	-
	T $1.54/cy		=	$4970/a
Daily output = 560 cy/day				
3. Protective layer fill, select fill Crew (B15)	L 0.81	3226.6 cy/a	=	2610
	E 1.45		=	4680
	M 5.00		=	16,130
	T $7.26/cy		=	$23,420/a
Daily output = 600 cy/day				
4. Clay liner, native clay fill Crew (B15)	L 0.81	3226.6 cy/a	=	2610
	E 1.45		=	4680
	M 1.00-4.00		=	3230-12,900
	T $3.30-6.30/cy		=	$10,500-20,200/a
Daily output = 600 cy/day				

Table 27 (Cont'd)

	Activity		Unit Cost	Multiplier		Cost/Acre
5.	Compaction Crew (B10G)	L	0.63	3226.6 cy/a	=	2030
		E	0.66		=	2130
		M	-		=	-
		T	$1.29/cy		=	$4160/a

Daily output = 360 cy/day

6. Liner material unit costs - includes installation, no breakdown available* (Multiplier: 4840 sy/a)

Bentonite, 2" layer spread & compacted	$1.40	=	6780
PVC, 20 mil, installed	$1.30-2.00	=	6300-9690
Chlorinated polyethylene membrane 20-30 mil, installed	$2.40-3.20	=	11,600-15,500
Elasticized polyolefin membrane, installed	$2.70-3.60	=	13,100-17,400
Hypalon membrane, 30 mil, installed	$6.50	=	31,500
Neoprene membrane, installed	$5.00	=	24,200
Ethylene propylene rubber membrane, installed	$2.70-3.50	=	13,100-17,000
Butyl rubber membrane, installed	$2.70-3.80	=	13,100-18,400
Cost range -	$1.30-6.50/sy	=	$ 6,300-31,500/a

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Clay liner (estimates from appropriate activity above)	$6000-12,000/a	$12,000-15,000/a	$3000-13,000/a	$21,000-40,000/a
Synthetic Liner	**	**	**	
Excavation	$6000-12,000/a	$12,000-15,000/a	$16,000/a	$34,000-43,000/a
Liners	N/A	N/A	N/A	$ 6,000-31,000/a
				$40,000-74,000/a

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*Manual for Remedial Actions at Waste Disposal Sites (JRB Associates, 1980).
**Breakdown unavailable.

Table 28

Advantages, Disadvantages, and Restrictions in Using Synthetic and Natural Liner Materials

Material	Advantages	Disadvantages	Restrictions
Clay	If available on-site or nearby, economically more attractive.	May crack under differential settling and weathering.	Can only be installed before landfilling. Performance must be monitored.
Synthetic materials	May be necessary in areas where clay is unavailable.	Relatively expensive. May interact adversely with leachate, causing failure.	Can only be installed before landfilling. Performance must be monitored.

Table 29

Advantages, Disadvantages, and Restrictions in Using Leachate Control Systems

Function	Advantages	Disadvantages	Restrictions
Control leachate seeps.	Operation costs low.	Continuous and precise monitoring required.	Not suited to poorly permeable soils.

Table 30

Costs for Impervious Clay Trenches

	Activity		Unit Cost	Multiplier		Cost/ly
1.	Trench excavation	L	0.22	13.33 cy/ly	=	2.93
	Crew (B12D)	E	0.78		=	10.40
		M	-		=	-
		T	$1.00/cy		=	$13.30/ly
	Daily output = 1400 cy/day					
2.	Barrow excavation, native clay	L	0.81	13.33 cy/ly	=	10.80
		E	1.45		=	19.30
	Crew (B15)	M	1.00-4.00		=	13.30-53.30
		T	$3.30-6.30/cy		=	$44.00-84.00/ly
	Daily output = 600 cy/day					
3.	Compaction*	L	0.63	13.33 cy/ly	=	8.40
	Crew (B10G)	E	0.66		=	8.80
		M	-		=	-
		T	$1.29/cy		=	$17.20/ly
	Daily output = 360 cy/day					
4.	Grading of excavated earth	L	0.41	13.33 cy/ly	=	5.50
		E	1.13		=	15.10
	Crew (B10M)	M	-		=	-
		T	$1.54/cy		=	$20.50/ly
	Daily output = 560 cy/day					

*Compaction by roller and dozer may not be possible, so cost may vary.

Table 31

Costs for Slurry Trench

Slurry Trench - bentonite slurry backfilled

Total cost = \$226-415/cy = \$3000-5600/ly
(cost reflects installation, materials, equipment, etc.)
Daily output = N/A

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Clay trench	\$27.60/ly	\$53.60/ly	\$13.30-53.30/ly	\$ 95-135/ly
Slurry trench	N/A	N/A	N/A	\$3000-5000/ly

Table 32

Advantages, Disadvantages, and Restrictions in Constructing Trenches for Protecting Groundwater

Function	Advantages	Disadvantages	Restrictions
In areas of completed landfilling, provides impermeable barrier to leachate or groundwater migration.	Properly designed and maintained, little or no maintenance required. Most cost effective and proven in preventing leachate movement.	Require expensive pre-construction geotechnical evaluation. Expensive: specialty equipment required.	Suited to areas of completed landfilling where depth of poorly permeable soil is low.

Table 33

Costs for Grouting

Multipliers: Volume of grout = 15.54 cy/ly
419.6 cf/ly

Activity		Unit Cost	Multiplier		Cost/ly
1. Installation of grout curtain, 1:1 mix of sand and cement	L	8.00-19.00	419.6 cf/ly	=	3360-7970
	E				
	M	4.20-5.00		=	1760-2100
		T$12.20-24.00/cf		=	$5120-10,100/ly

Daily output = N/A

2. Other material costs				
Portland Cement	$ 192/yd^3	15.54 cy/ly	=	2980
Bentonite	$ 252/yd^3		=	3920
Silicate: 20%	$ 353/yd^3		=	5490
30%	$ 424/yd^3		=	6590
40%	$ 555/yd^3		=	8620
Lignochrome	$ 313/yd^3		=	4860
Acrylamide	$1340/yd^3		=	20,800
Urea Formaldehyde	$1150/yd^3		=	17,900
		Cost Range	=	$2980-20,800/ly

TOTAL COST:

	Labor & Equipment	Materials	Total
Grout curtain	$3360-7970/ly	$1760-20,800/ly	$1500-29,000/ly

Table 34

Advantages, Disadvantages, and Restrictions in Using Grouting to Protect Groundwater

Function	Advantages	Disadvantages	Restrictions
Decreases soil/rock permeability and seals.	Can be formulated to set within a few seconds.	Sophisticated specialty machinery required (high equipment mobilization costs). Not proven.	Not suited to poorly permeable soil. Cannot be used in clayey soils.

Table 35

Costs for Subsurface Drains

Multipliers: Volume of gravel trench = 8.33 cy/ly
Volume of clay trench = 8.33 cy/ly

Activity		Unit Cost	Multiplier		Cost/ly
1. Gravel trench excavation Crew (B12D)	L	0.22	8.33 cy/ly	=	1.83
	E	0.78		=	6.50
	M	-		=	-
	T	$1.00/cy		=	$8.30/ly
Daily output = 1400 cy/day					
2. Clay piping, 6" perforated vitrified sewer Crew (B20)	L	2.53	3 lf/ly	=	7.58
	E	-		=	-
	M	2.09		=	6.27
	T	$4.62/lf		=	$13.90/ly
Daily output = 200 lf/day					
3. Borrow excavation, 3/4" crushed stone fill Crew (B15)	L	0.81	8.33 cy/ly	=	6.75
	E	1.45		=	12.10
	M	6.05		=	50.40
	T	$8.31/cy		=	$69.20/ly
Daily output = 600 cy/day					

Table 35 (Cont'd)

	Activity		Unit Cost	Multiplier		Cost/ly
4.	Clay trench excavation Crew (B12D)	L	0.22	8.33 cy/ly	=	1.83
		E	0.78		=	6.50
		M	-		=	-
		T	$1.00/cy		=	$8.30/ly
	Daily output = 1400 cy/day					
5.	Borrow excavation, native clay fill Crew (B15)	L	0.81	8.33 cy/ly	=	6.75
		E	1.45		=	12.10
		M	1.00-4.00		=	8.33-33.30
		T	$3.30-6.30/cy		=	$27.50-52.50/ly
	Daily output = 600 cy/day					
6.	Grading of excavated earth (each trench) Crew (B10M)	L	0.41	8.33 cy/ly	=	3.42
		E	1.13		=	9.41
		M	-		=	-
		T	$1.54/cy		=	$12.80/ly
	Daily output = 560 cy/day					

7. Additional costs

A. Pump - centrifugal, 4-5 gpm, 25-25' lift
$300 ea (does not include installation)*

B. Piping - steel (Sch 40) 1"-8"
Crew (Q1) or (Q2)

L	3.00-27.00
E	-
M	1.50-16.00
T	$4.70-43.00/lf

Daily output = 27-89 lf/day

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Gravel trench	$19.60/ly	$28.00/ly	$56.70/ly	$104/ly
Clay trench	$12.00/ly	$28.00/ly	$ 8.30-33.30/ly	$ 48-73/ly

*Manual for Remedial Actions at Waste Disposal Sites (JRB Associates, 1980).

Table 35 (Cont'd)

Additional costs:

	Labor	Equipment	Materials	Total
Pump			$300 ea	
Piping	$3.00-27.00/lf	-	$1.50-16.00/lf	$4.70-43.00/lf

Table 36

Advantages, Disadvantages, and Restrictions in Constructing Subsurface Drainage Systems

Function	Advantages	Disadvantages	Restrictions
Intercept contaminated groundwater leaving the landfill.	Low operation costs.	Continuous monitoring required.	Most effective when depth to groundwater is 20 ft (areas of shallow perched water), and frost zone is not too deep.

Table 37

Costs of Dewatering Systems

Activity		Unit Cost
1. Wellpoints		
2"		$22.50/1f + $15 for fittings
4"		$30.00/1f + $28 for fittings
2. Piping costs, 1"-8" Sch 40 steel Crew (Q1) or (Q2)	L	3.00-27.00
	E	-
	M	1.50-16.00
	T	$4.70-43.00/1f
3. Pumps		
A. Centrifugal pump, 4-5 gpm, 15-25' lift, 1/4 hp		$300 ea
B. Deep well, jet ejector pump, 120' lift, 5 gpm, 3/4 hp		$500 ea
C. 4" submersible pump, 180' lift, 23 gpm		$1175 ea
4. Well excavation, 4"-6" diam.		$8.50/1f
5. Well casing, 4"-6" PVC		$4.10-5.60/1f

Table 38

Advantages, Disadvantages, and Restrictions in Using Extraction Wells and Well Point Systems in Dewatering to Protect Groundwater

Technology	Function	Advantages	Disadvantages	Restrictions
Extraction wells	Plume containment.	High design flexibility. Systems easily dismantled & reinstalled. Construction costs usually lower than for groundwater barriers.	Performance inadequate in fine silty soils. Higher O&M than for groundwater barriers. Extensive monitoring may be required.	Best suited to areas of permeable bedrock where impermeable barriers cannot contain vertical migration.
Well-point systems	Lower water table to prevent contamination.	(As above)	(As above)	(As above)

Table 39

Costs for Leachate Collection

Multipliers: Volume of trench = 1 cy/ly
Volume of sump tank = 1000-1500 gal = 5-75 cy

Activity		Unit Cost	Multiplier		Cost/ly
1. Trench excavation Crew (B11C)	L	1.93	1 cy/ly	=	1.93
	E	0.89		=	0.89
	M	-		=	-
	T	$2.82/cy		=	$2.82/ly

Daily output = 150 cy/day

Table 39 (Cont'd)

	Activity		Unit Cost	Multiplier		Cost/ly
2.	Drainage pipe, 4"	L	1.91	3 ly/ly	=	5.73
	A. Vitrified clay	E	-		=	-
	Crew (B20)	M	1.49		=	4.47
		T	$3.40/ly		=	$10.20/ly
	Daily output = 265 ly/day					
	B. PVC, class 160	L	2.53	3 lf/ly	=	7.59
	Crew (B20)	E	-		=	-
		M	1.54		=	4.62
		T	$4.07/1f		=	$12.20/ly
	Daily output = 200 ly/day					
3.	Borrow excavation,	L	0.81	1 cy/ly	=	0.81
	3/4" crushed	E	1.45		=	1.45
	stone fill	M	6.05		=	6.05
	Crew (B15)					
		T	$8.31/cy		=	$8.31/ly
	Daily output = 600 cy/day					
4.	Grading excavated	L	0.41	1 cy/ly	=	0.41
	earth	E	1.13		=	1.13
	Crew (B10M)	M	-		=	-
		T	$1.54/cy		=	$1.54/ly
	Daily output = 560 cy/day					
5.	Collection sump	L	0.86	5-75 cy/ea	=	4.30-64.50
	excavation	E	0.92		=	4.60-69.00
	Crew (B12A)	M	-		=	-
		T	$1.78/cy		=	$8.90-134 ea
	Daily output = 360 cy/day					

Table 39 (Cont'd)

Activity		Unit Cost	Multiplier	Cost/ly
6. Sump tank, 1000-15,000				
gal capacity	L	74-737		
A. Precast concrete	E	7.40-273		
Crew (B21)	M	209-6050		
or (B13)				
	T	$290-7070 ea		
Daily output = 1-8 ea/day				
B. Fiberglass	L	344-1720		
Crew (Q7)	E	-		
	M	3060-9350		
	T	$3400-11,100 ea		
Daily output = 0.4-2 ea/day				
7. Pumps, 4"	L	536-655		
submersible,*	E	54-66		
1-5 hp, 1.7-1494 gpm	M	580-1650		
Crew (B21)				
	T	$1170-2370 ea		
Daily output = 1 ea/day				
8. Piping*	L	3.00-27.00		
1-8" Sch 40 steel	E	-		
Crew (Q1)	M	1.50-16.00		
or (Q2)				
	T	$4.50-43.00/1f		
Daily output = 27-89 ly/day				

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Drainage trench	$ 8.90-10.70/ly	$ 3.50/ly	$ 10.50-10.70/ly	$ 22.90-24.90/ly
Sump	$ 78-1800 ea	$12-342 ea	$209-9350 ea	$ 300-12,000 ea
Pump	$536-655 ea	$54-66 ea	$580-1650 ea	$1100-2400 ea
Piping	$ 3-27/1f	$ -	$ 1.50-16/1f	$ 4.50-43/1f

*Pump and piping requirements are highly variable; depend on maintenance, type of materials to be pumped (corrosiveness, viscosity, etc.), and quantity to be pumped.

Table 40

Advantages, Disadvantages, and Restrictions in Collecting Leachate

Function	Advantages	Disadvantages	Restrictions
Intercepts subsurface leachate to treatment or recirculation system.	Operation costs low. Less risk to install and operate than impervious liners.	Continuous and precise monitoring required.	Limited applicability where soils are of low permeability. Must be properly treated and discharged.

Table 41

Costs for Leachate Treatment

Activity	Unit Cost x $1000
Activated sludge treatment with clarifier	125-500
Ammonia stripping	50-200
Anaerobic facultative lagoons	175-450
Biological seeding with pure oxygen activation	230-300
Carbon adsorption with 1 regeneration	75-200
Chlorination	25-75
Equalization	25-75
Ion exchange	200-500
Liquid ion exchange	200-500
Precipitation/floc sedimentation	40-100
Pure oxygen activated sludge	75-400
Rotating biological disc and clarifier	75-500
Trickling filter	75-200
Wet air oxidation*	40-100

*Manual for Remedial Actions at Waste Disposal Sites (JRB Associates, 1980).

Table 42

Advantages, Disadvantages, and Restrictions in Using Liners for Gas Control

Function	Advantages	Disadvantages	Restrictions
Contains gas flow.	Clay materials, if available on-site or nearby may be economical.	May crack under differential settling and weathering. Synthetic materials are expensive, if clays are not available.	Must be installed before landfilling.

Table 43

Costs for Gravel Trench

	Activity		Unit Cost	Multiplier		Cost/ly
1.	Trench excavation Crew (B12D)	L	0.22	13.33 cy/ly	=	2.93
		E	0.78		=	10.40
		M	-		=	-
		T	$1.00/cy		=	$13.30/cy
	Daily output = 1400 cy/day					
2.	Borrow excavation, 3/4" crushed stone fill Crew (B15)	L	0.81	13.33/cy	=	10.80
		E	1.45		=	19.30
		M	6.05		=	80.70
		T	$8.31/cy		=	$111/ly
	Daily output = 600 cy/day					
3.	PVC liner, 20 mil*	L**	0.30-0.50	8.67 sy/ly	=	2.60-4.34
		E	-		=	-
		M**	1.00-1.50		=	8.67-13.00
		T	$1.30-2.00/sy		=	$11.30-17.30/ly
	Daily output = N/A					

*Manual for Remedial Actions at Waste Disposal Sites (JRB Associates, 1980).
**Assumed labor and material cost distribution.

Table 43 (Cont'd)

	Activity		Unit Cost	Multiplier		Cost/ly
4.	Grading of excavated earth Crew (B10M)	L	0.41	13.33 cy/ly	=	5.47
		E	1.13		=	15.10
		M	-		=	-
		T	$1.54/cy		=	$20.50/ly
	Daily output = 560 cy/day					
5.	Optional-vent pipes, 1-1/2 to 6" PVC, class 160 Crew (B20)	L	1.69-2.81			
		E	-			
		M	0.32-2.75			
		T	$2.01-5.56/lf			
	Daily output = 180-300 lf/day					

Table 44

Costs for Vent Well

	Activity		Unit Cost	Multiplier		Cost/ly
1.	Well excavation	L*	2.50-5.50		=	2.50-5.50
		E*	2.50-5.50		=	2.50-5.50
		M	-		=	-
		T	$5.00-11.00/lf		=	$5.00-11.00/lf
	Daily output = N/A					
2.	Borrow excavation, 3/4" crushed stone fill Crew (B15)	L	0.81	0.12 cy/lf	=	0.10
		E	1.45		=	0.17
		M	6.05		=	0.73
		T	$8.31/cy		=	$1.00/lf
	Daily output = 600 cy/day					

---

*Assumed labor and material cost distribution.

Table 44 (Cont'd)

Activity		Unit Cost	Multiplier		Cost/ly
3. PVC vent pipe, 1-1/2 to 6" PVC, class 160 Crew (B20)	L	1.69-2.81		=	1.69-2.81
	E	-		=	-
	M	0.32-2.75		=	0.32-2.75
	T	$2.01-5.56/lf		=	$2.01-5.56/lf

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Gravel trench	$21.70-23.60/lf	$44.80/lf	$89.30-98.00/lf	$155-166/ly
Optional ventpipe	$ 1.70-2.80/lf	$ -	$ 0.30-2.80/lf	$ 2.00-5.60/lf
Gravel ventwell	$ 4.30-8.40/lf	$ 2.70-5.70/lf	$ 1.00-3.50/lf	$ 8-18/lf

Table 45

Advantages and Restrictions in Venting Gases

Function	Advantages	Restrictions
Control convective subsurface migration of gases.	Relatively inexpensive.	Best used in small areas (5-6 acres).

Table 46

Costs for Pumped Wells

Activity		Unit Cost
1. Manifold piping, 6-8" galvanized steel Crew (Q2)	L	16.10-18.50/lf
	E	-
	M	19.10-27.50
	T	$35.20-46.00/lf
Daily output = 27-31 lf/day		
2. Fan, 500-2000 cu ft/min (8" H_2O)*		$1900-2050 ea

*Manual for Remedial Actions at Waste Disposal Sites (JRB Associates, 1980).

Table 47

Restrictions in Using Pumped Wells

Function	Restrictions
Control diffusive subsurface migration of gases.	Well suited in combination with gas recovery system.

Table 48

Costs for Monitoring

Activity	Unit Cost
Soil testing 10 samples/acre	2160.00/acre
Hydrometer analysis and specific gravity	60.00 ea
Seive analysis, washed	8.00 ea
unwashed	50.00 ea
Moisture content	8.00 ea
Permeability	50.00 ea
Proctor compaction	40.00 ea
Test wells - Gas probe included along with pressure measurement and three test wells/acre of at least 20 ft depth	20.00-28.00/ft

Table 49

Costs for Cable Canopy

Activity		Unit Cost
1. Wire rope Fiber core, 1/2" diameter		$0.70/lf (material only)
2. Support posts 3" diameter, 15' high Crew (B1)	L	20
	E	-
	M	206
	T	$226 ea
3. Concrete anchors Crew (C6)	L	5.17
	E	0.25
	M	40.00
	T	$45.40/cy

Table 50

Costs for Controlling Access

	Activity		Unit Cost	Multiplier		Total Cost
1.	Fence installation	L	3.19	800 lf	=	2550
	6' high with three	E	-		=	-
	strands barbed wire,	M	7.04		=	5630
	2" line posts @ 10'					
	on center;	T	$10.20/lf		=	$8180
	1-5/8" toprail					
	6 gauge galvanized steel wire					
	Crew (B1)					
	Daily output = 125 lf/day					
2.	Corner posts,	L	20.00	4 posts	=	80
	3" diameter,	E	-		=	-
	galvanized steel	M	82.50		=	330
	Crew (B1)					
		T	$102/post		=	$410
	Daily output = 20/day					
3.	Braces, galvanized steel	L	4.99	36 braces	=	180
		E	-		=	-
	Crew (B1)	M	19.80		=	713
		T	$25.00 ea		=	$890
4.	Gate for 6' fence,	L	5	60 lf	=	300
	1-1/2" frame,	E	-		=	-
	galvanized steel	M	33		=	1980
	Crew (B1) M					
		T	$38/lf		-	$2280
	Daily output = 80 lf/day					
5.	Concrete anchors,	L	5.17	8-0.44 cy	=	18.20
	2500 psi redimix,	E	0.25		=	0.90
	2' x 2' x 3' ea	M	40.00		=	140.80
		T	$45.40/cy		=	$160

TOTAL COSTS:

	Labor	Equipment	Materials	Total
Access control	$3130	-	$8800	$11,900

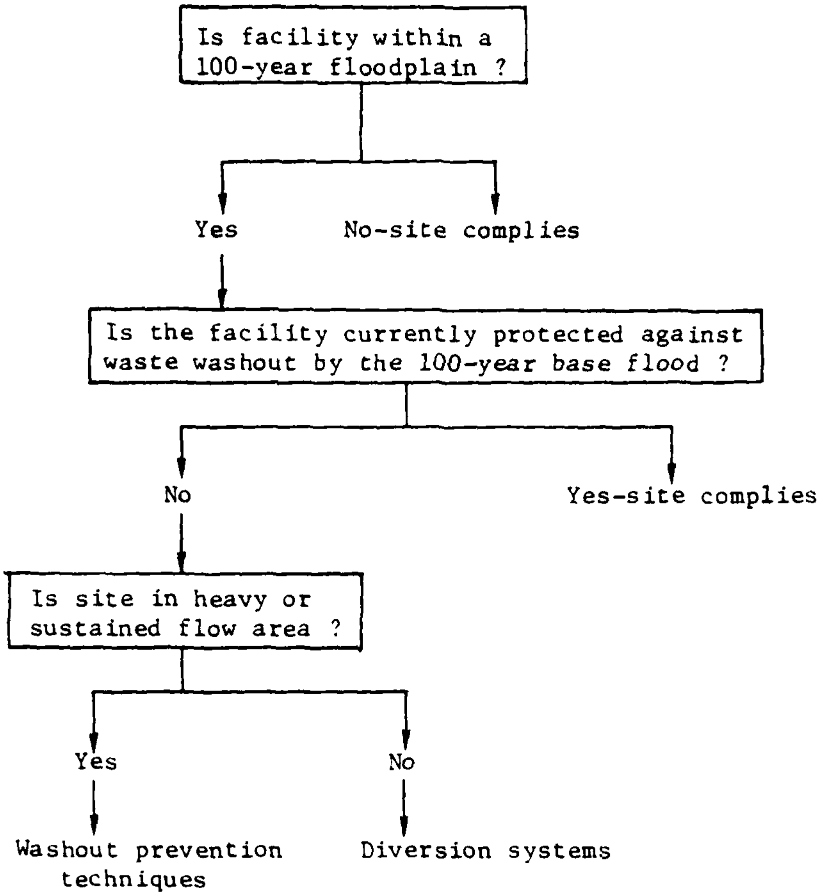


Figure 1. Decision flow for floodplain technologies.

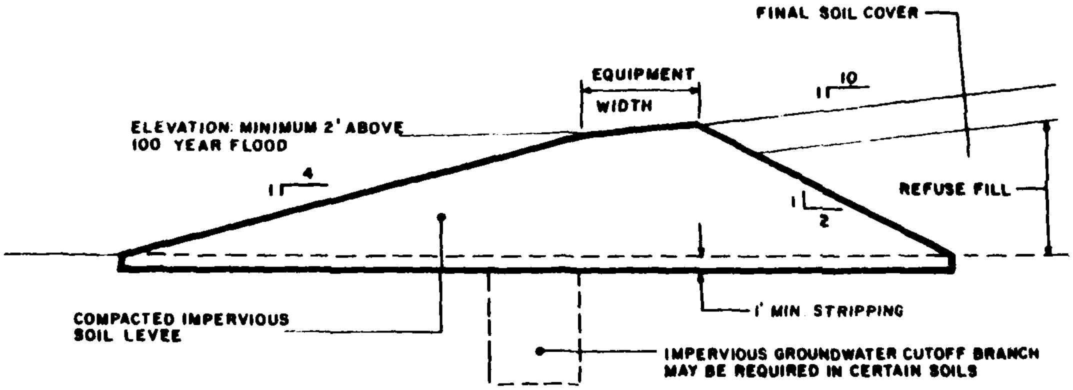


Figure 2. Typical levee design.

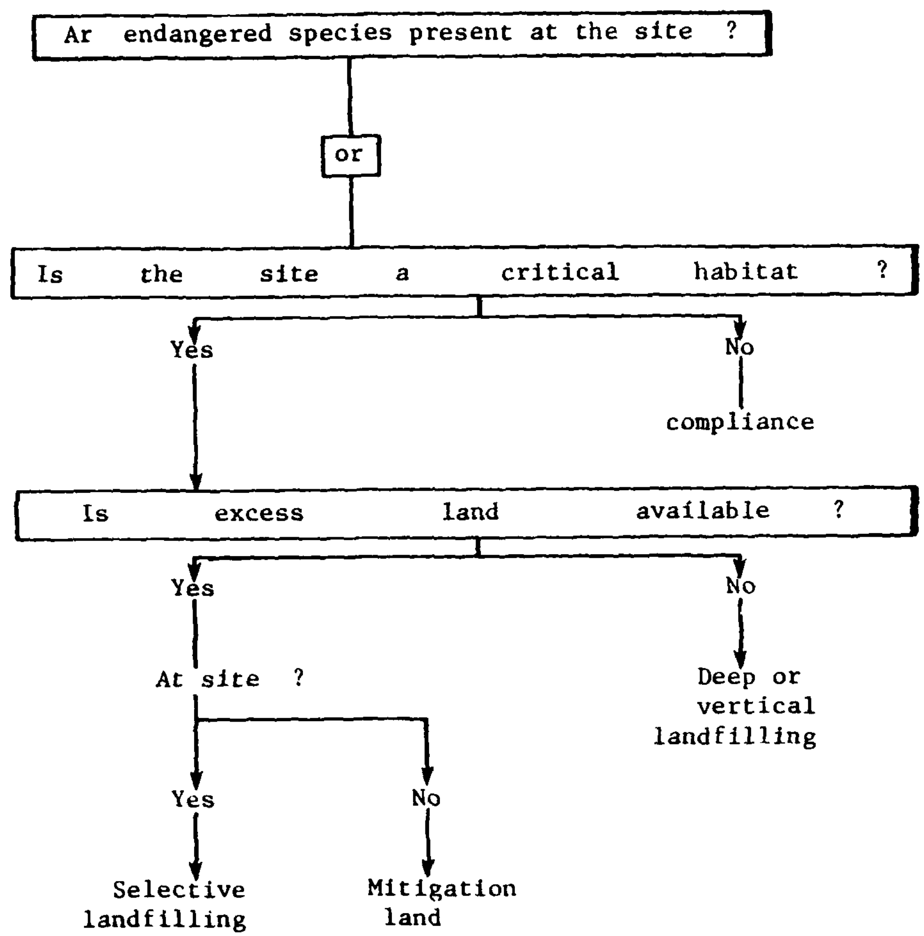


Figure 3. Decision flow for endangered species protection techniques.

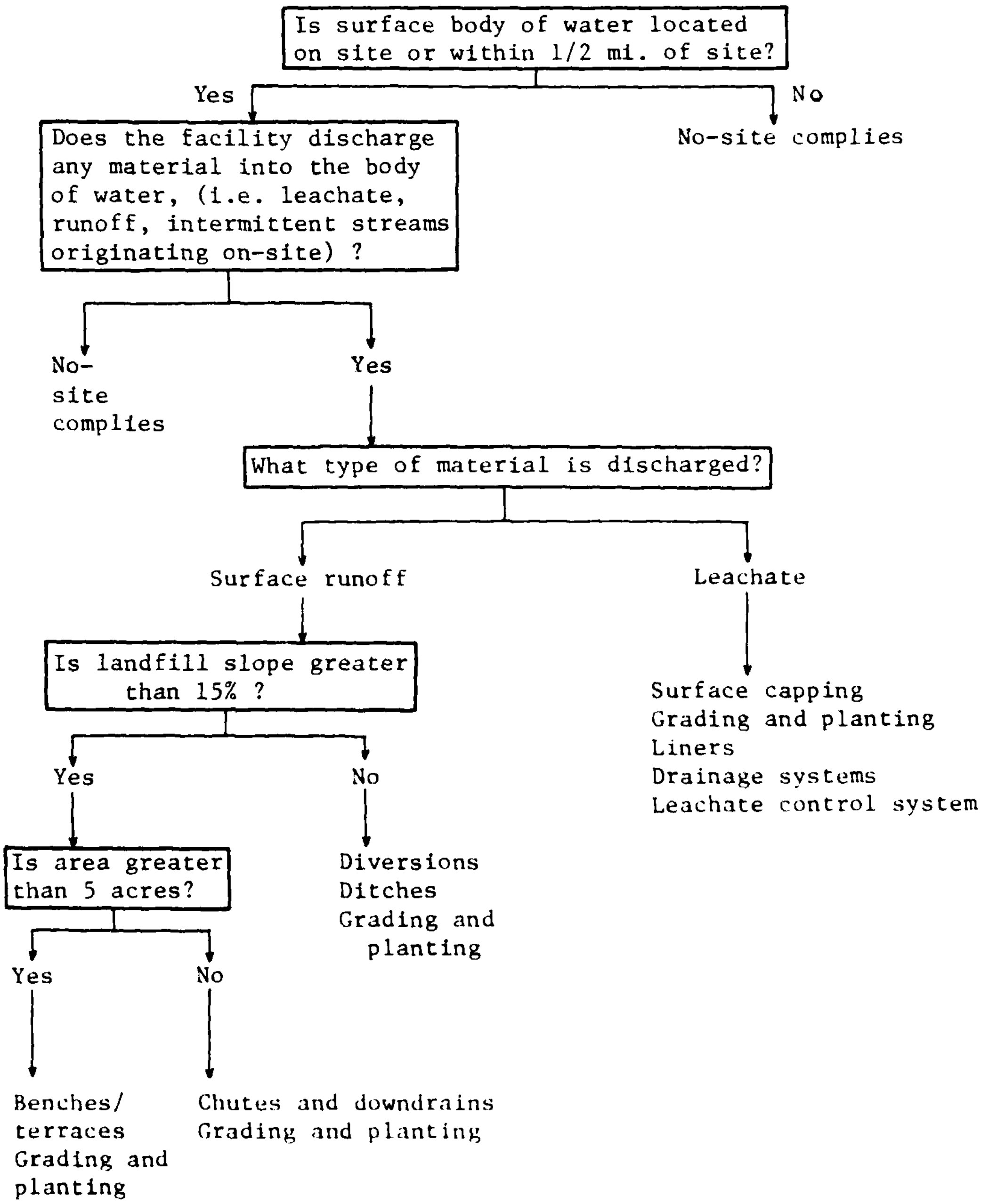


Figure 4. Decision flow for surface water technologies.

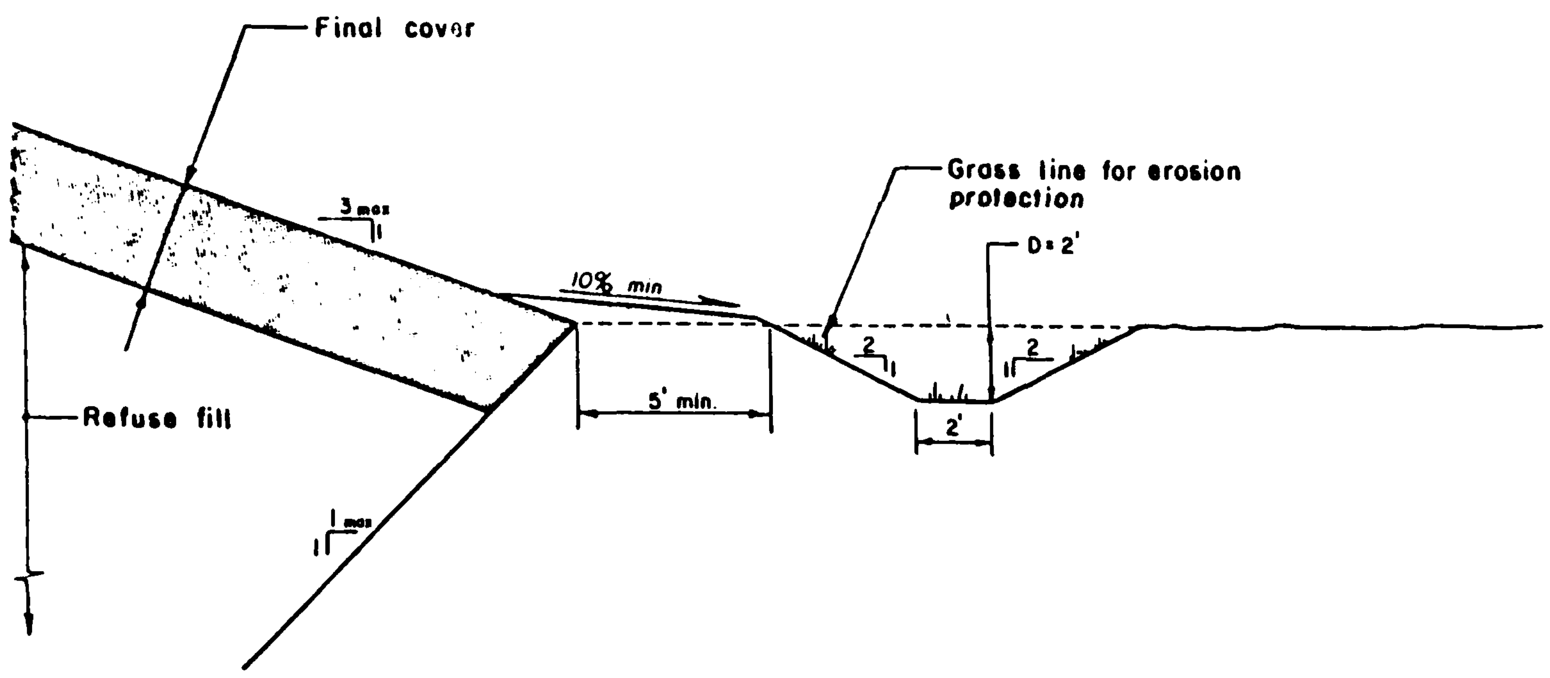


Figure 5. Typical ditch at base of disposal site.

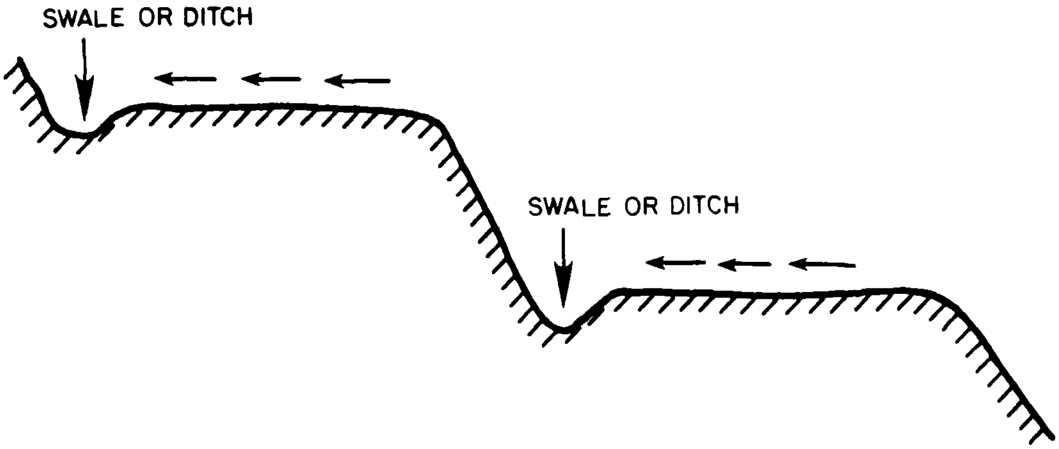


Figure 6. Bench terrace with reverse fall.

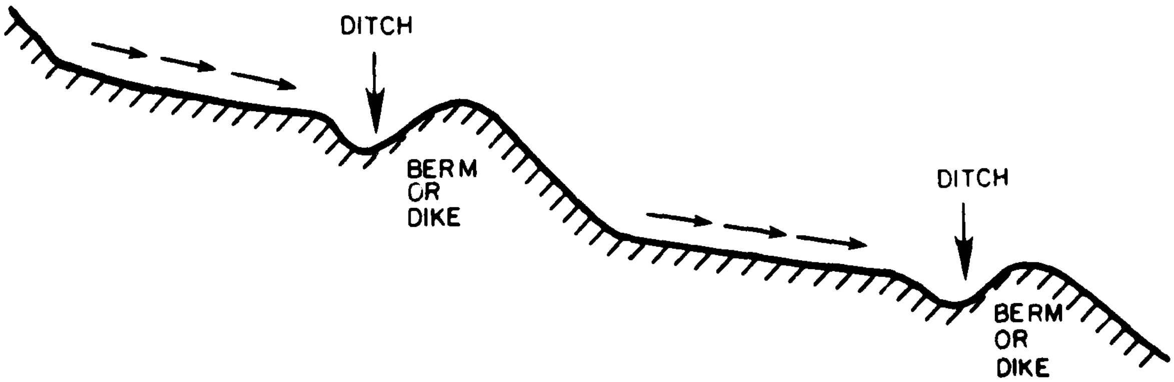


Figure 7. Bench terrace with natural fall.

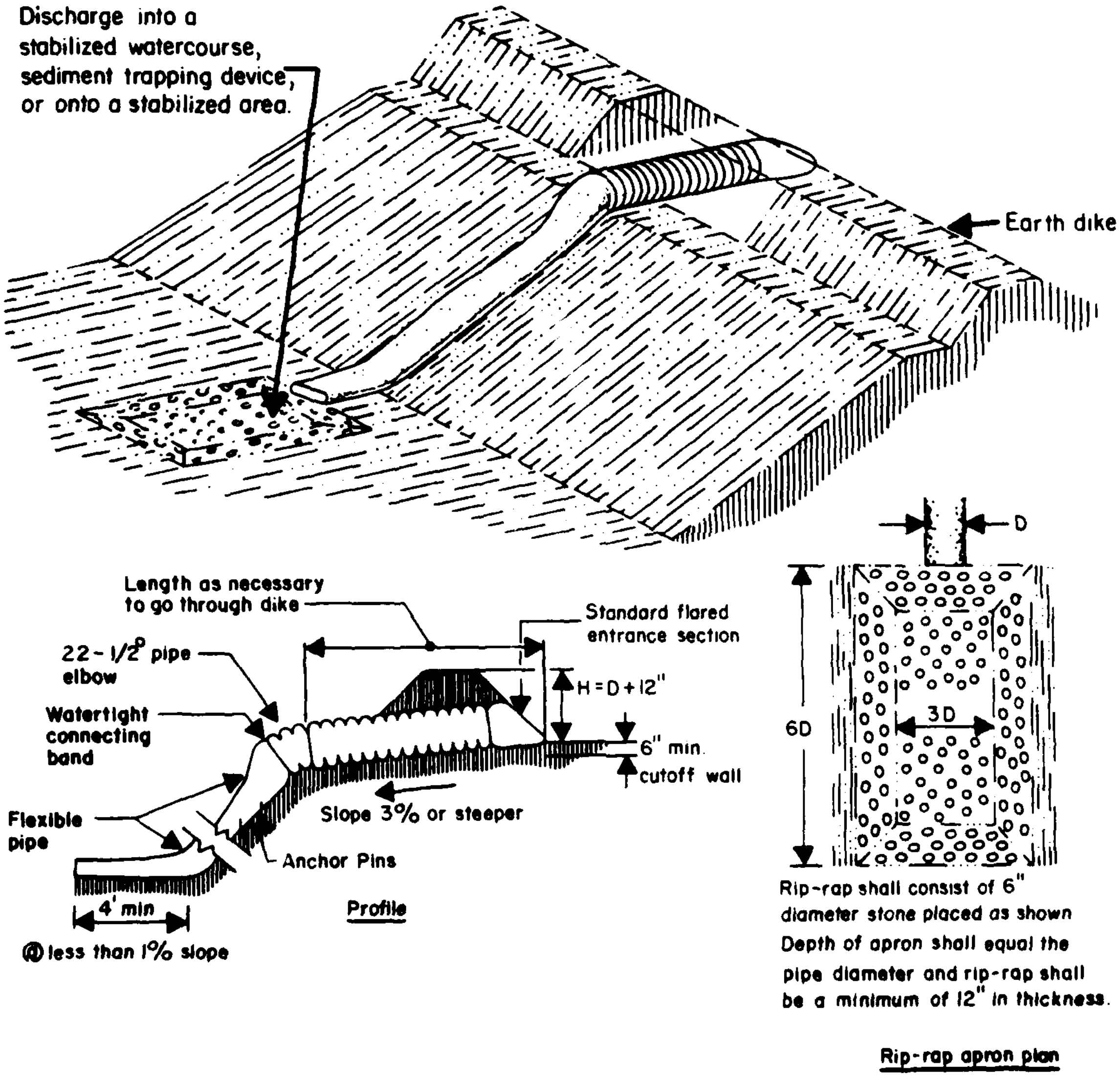


Figure 8. Flexible downdrain (from Erosion and Sediment Control: Surface Mining in the Eastern United States, EPA Technology Transfer [EPA, 1976]).

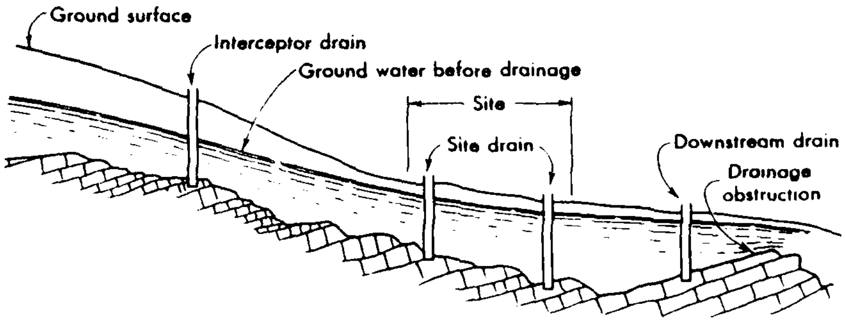


Figure 9. Drainage system layout (from Introductory Soil Mechanics and Foundations, Third Edition, by G. B. Sowers and G. F. Sowers [Copyright © 1970 by Macmillan Publishing Co., Inc.], p 184).

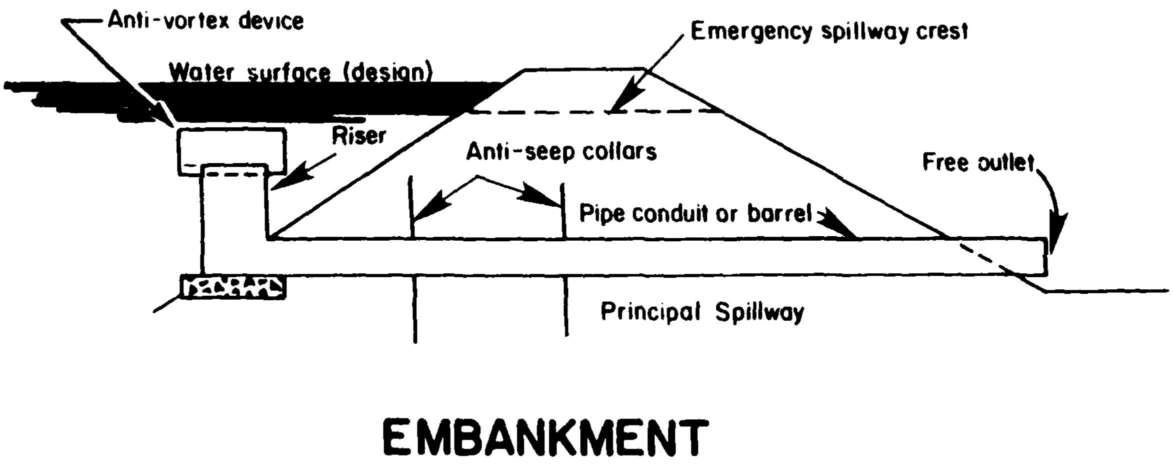


Figure 10. Typical design of a sediment basin embankment.

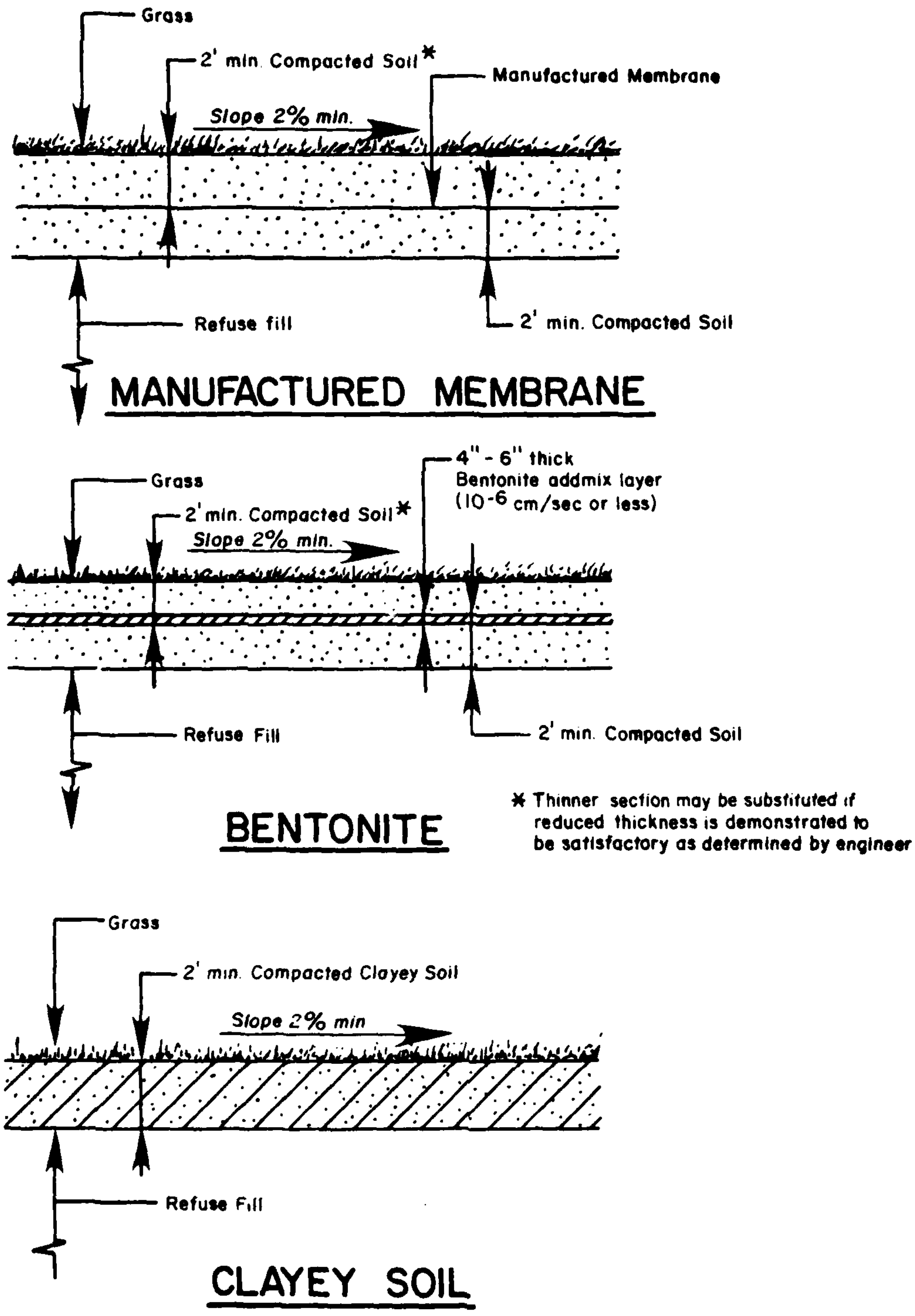


Figure 11. Surface capping alternatives.

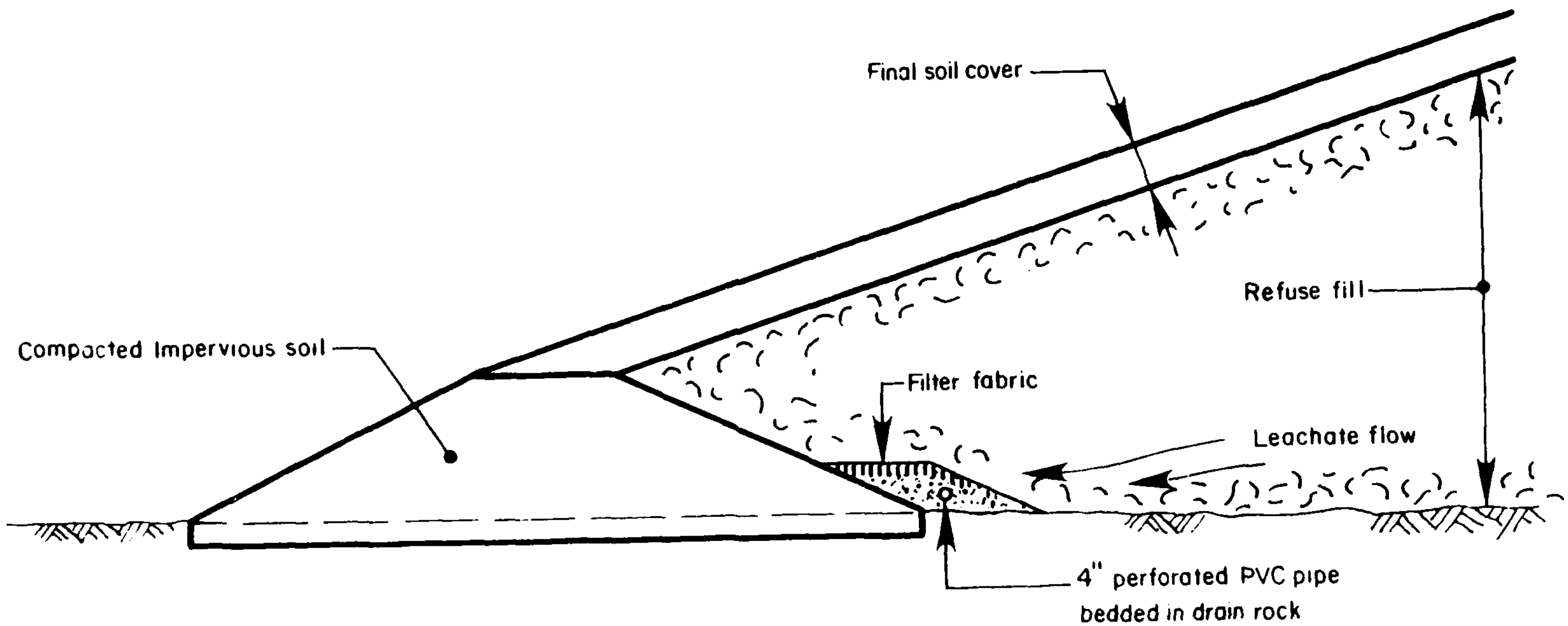
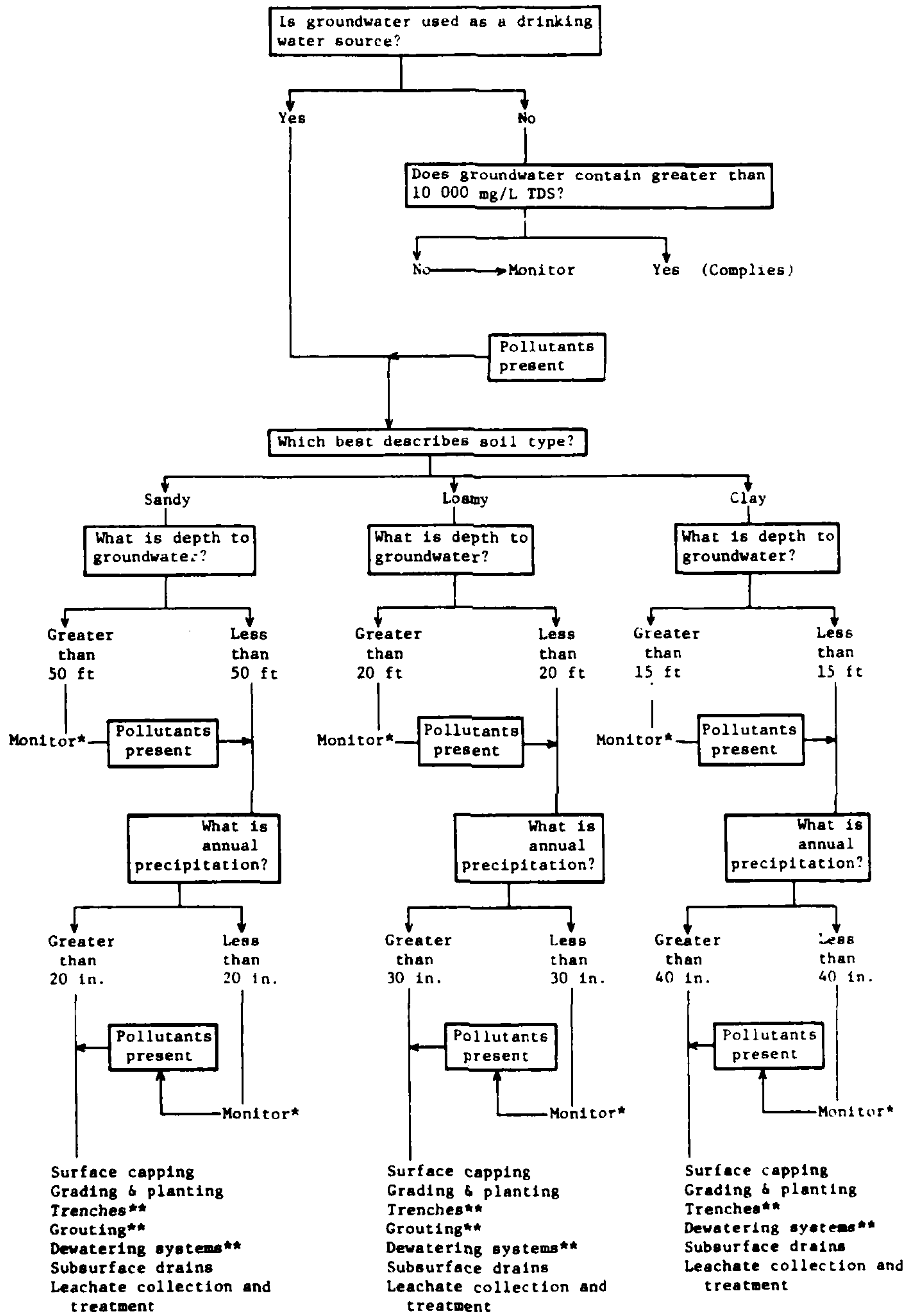


Figure 12. Control system for leachate seeps.



*If monitoring indicates presence of pollutants in groundwater proceed through decision.
**Conduct economic comparison to determine which technology to employ.

Figure 13. Decision flow for groundwater technologies.

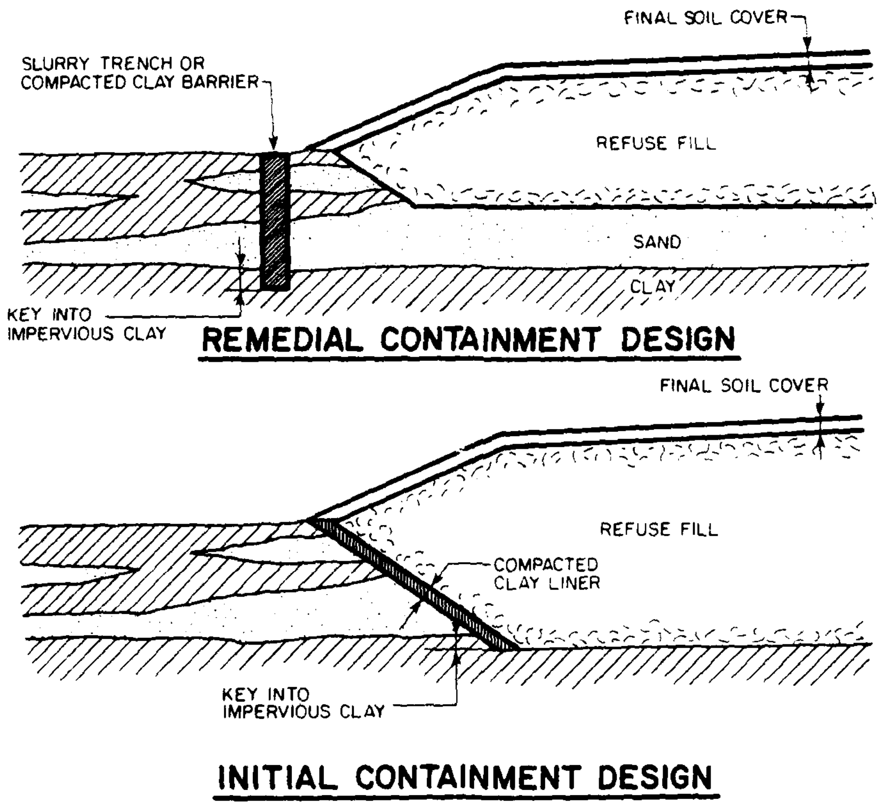


Figure 14. Trench placement.

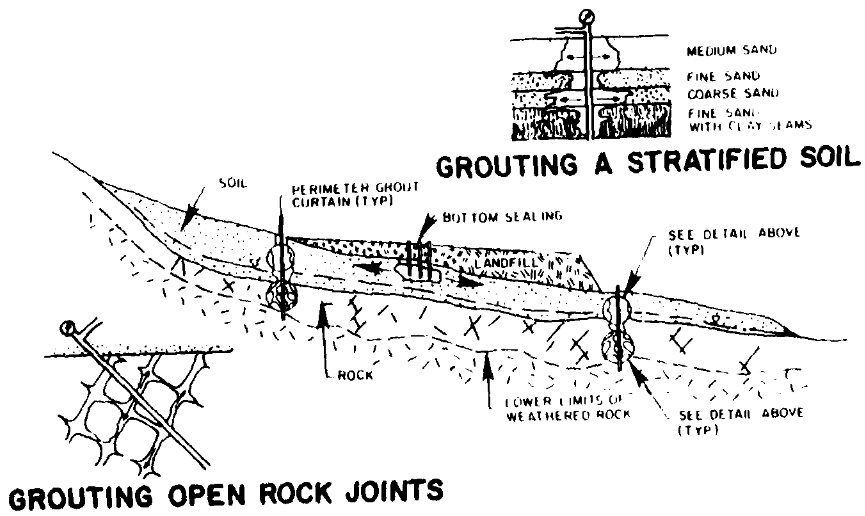


Figure 15. Grout curtain placement.

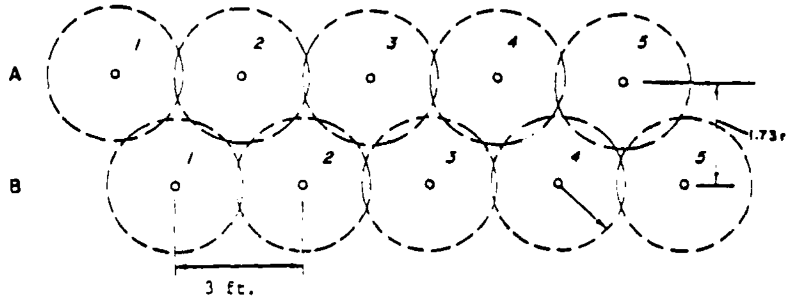


Figure 16. Typical two-row grid pattern for grout curtain.

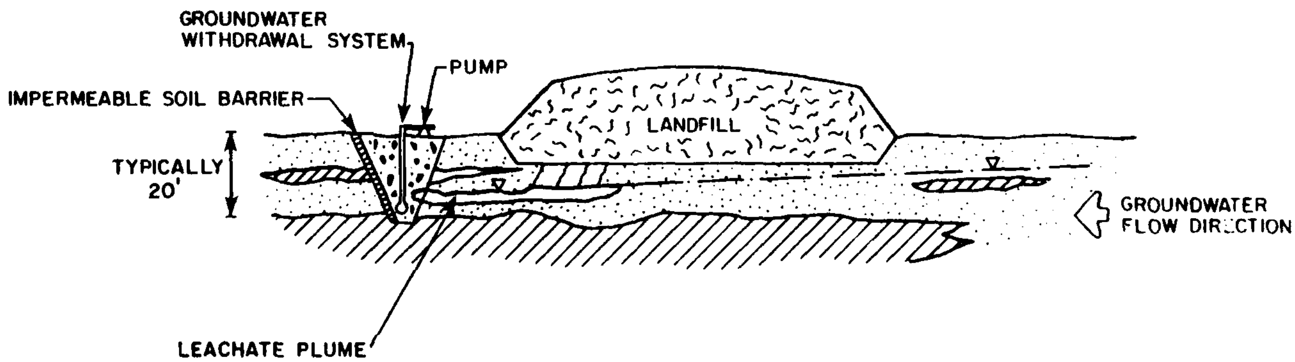


Figure 17. Subsurface drainage system.

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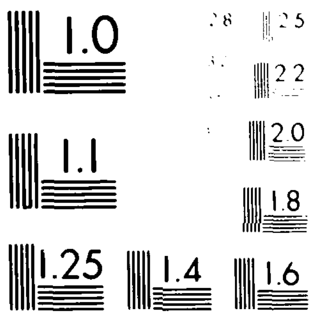
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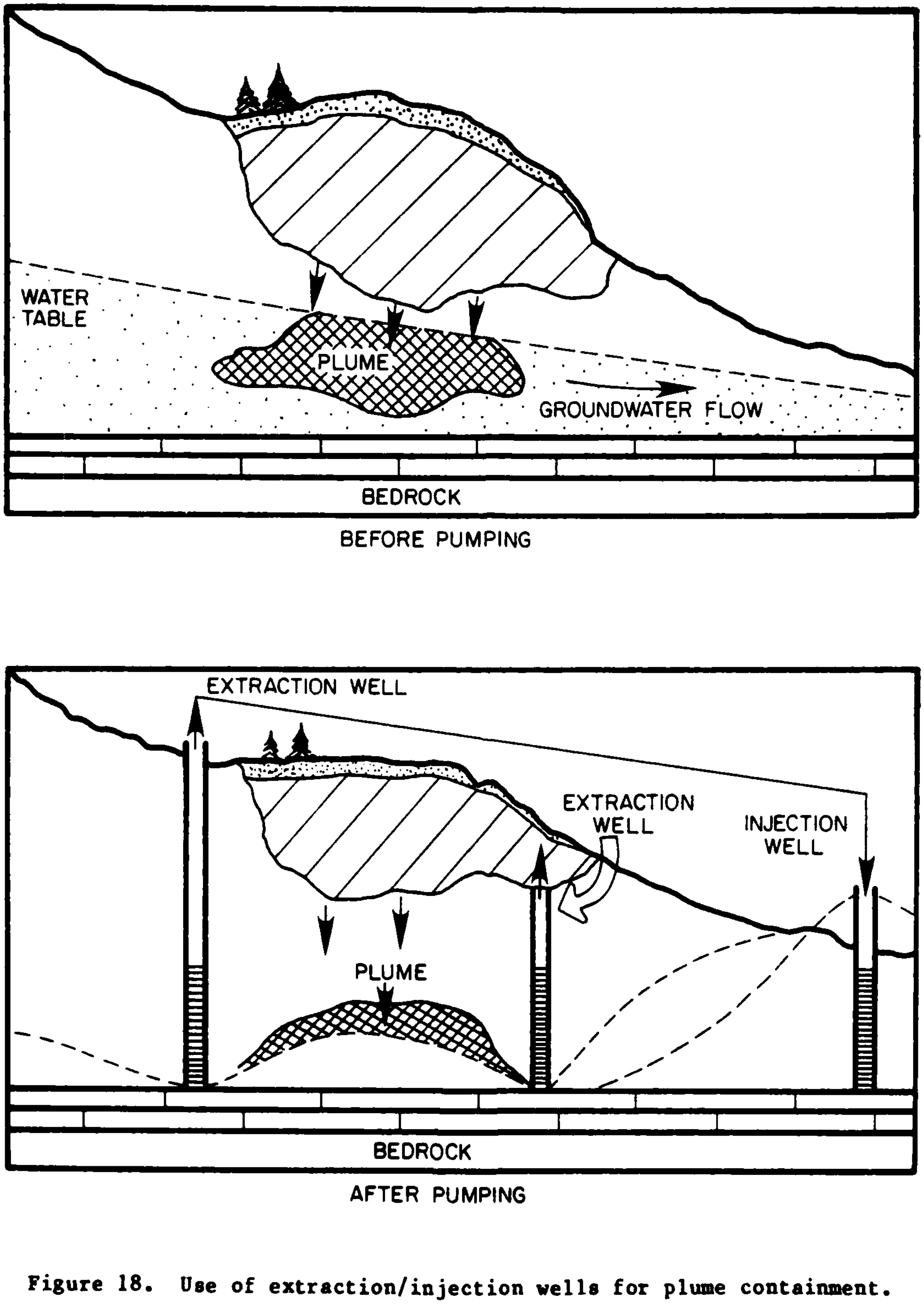

Figure 18. Use of extraction/injection wells for plume containment.

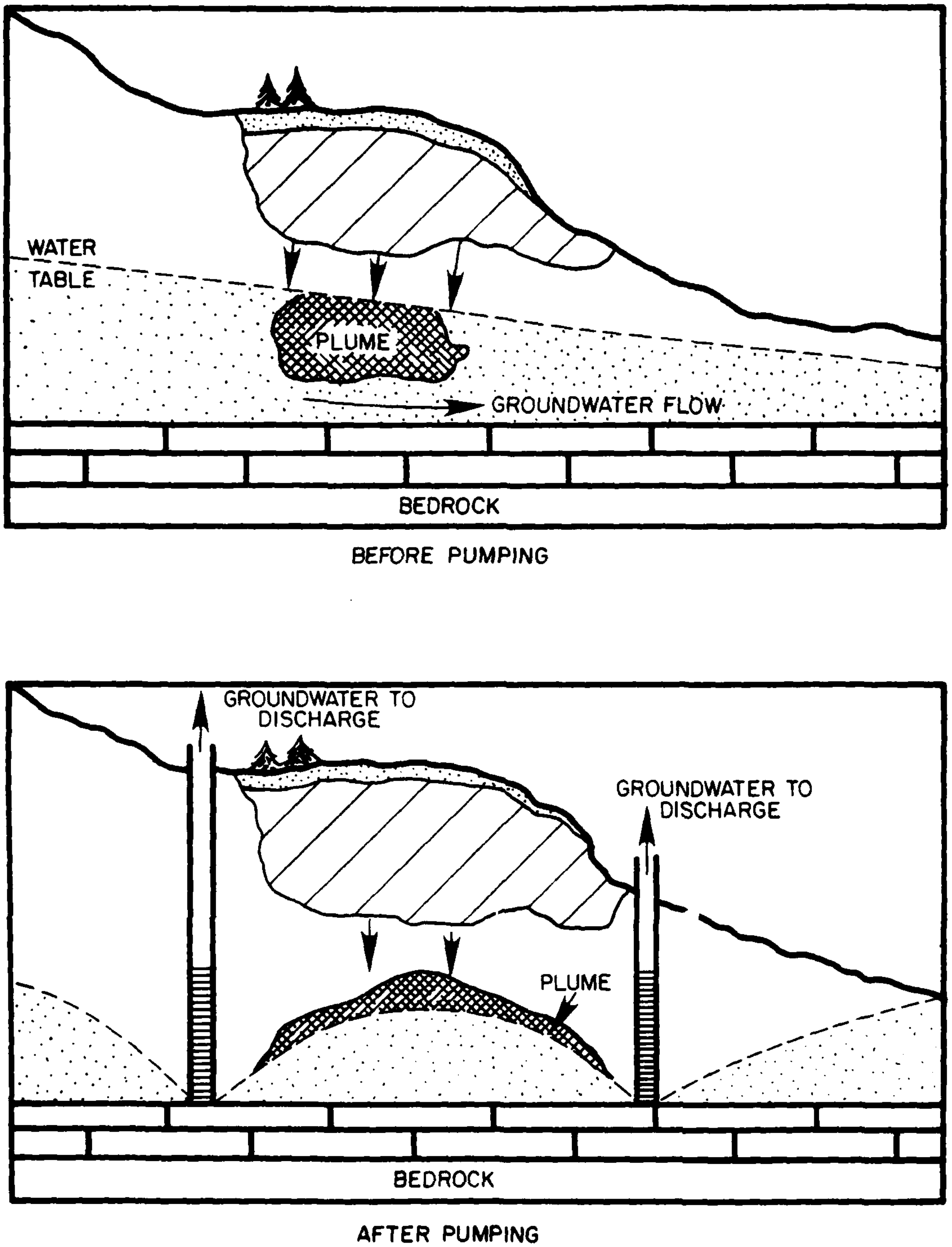

Figure 19. Groundwater pumping to contain plume (no recharge).

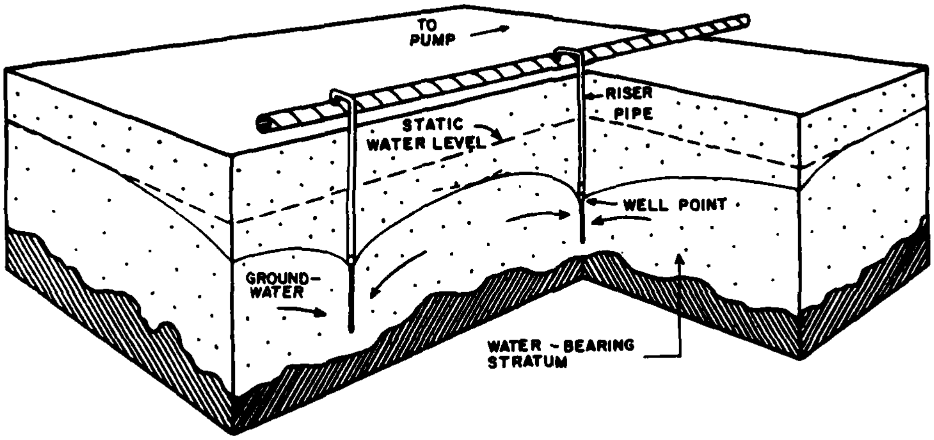

Figure 20. A well-point dewatering system.

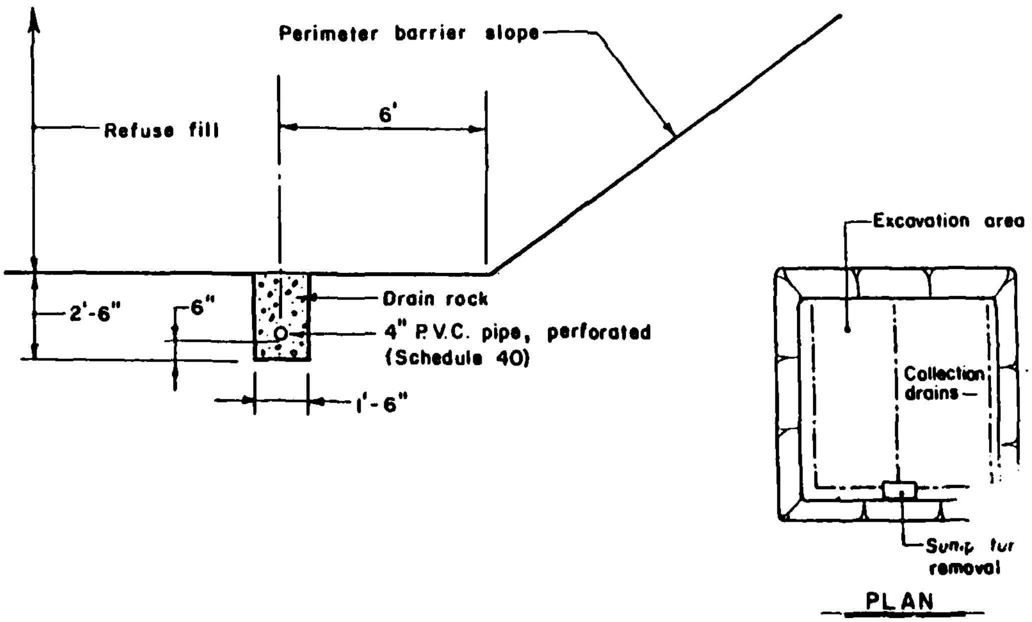

Figure 21. Leachate collection system.

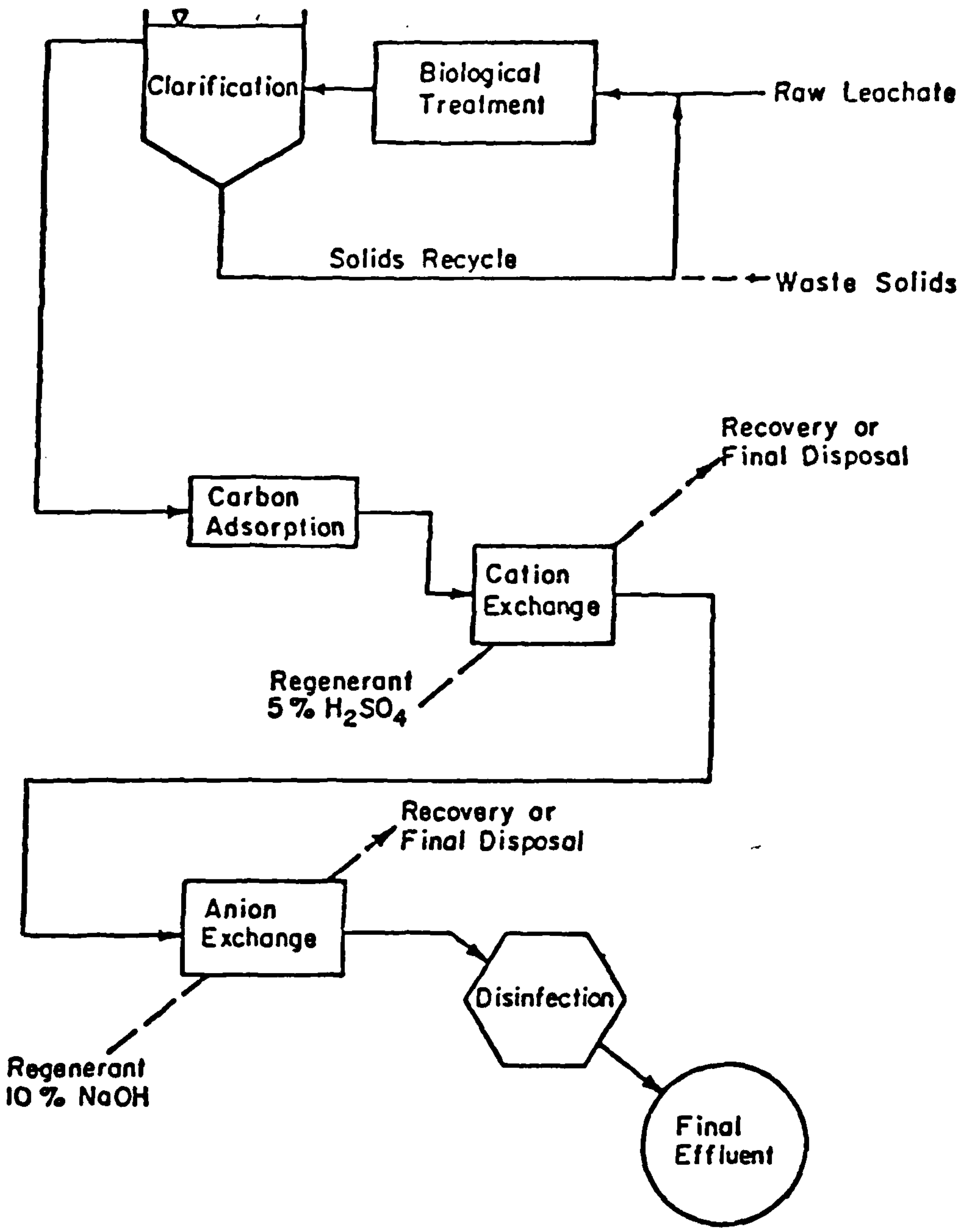

Figure 22. On-site treatment of unrecycled leachate.

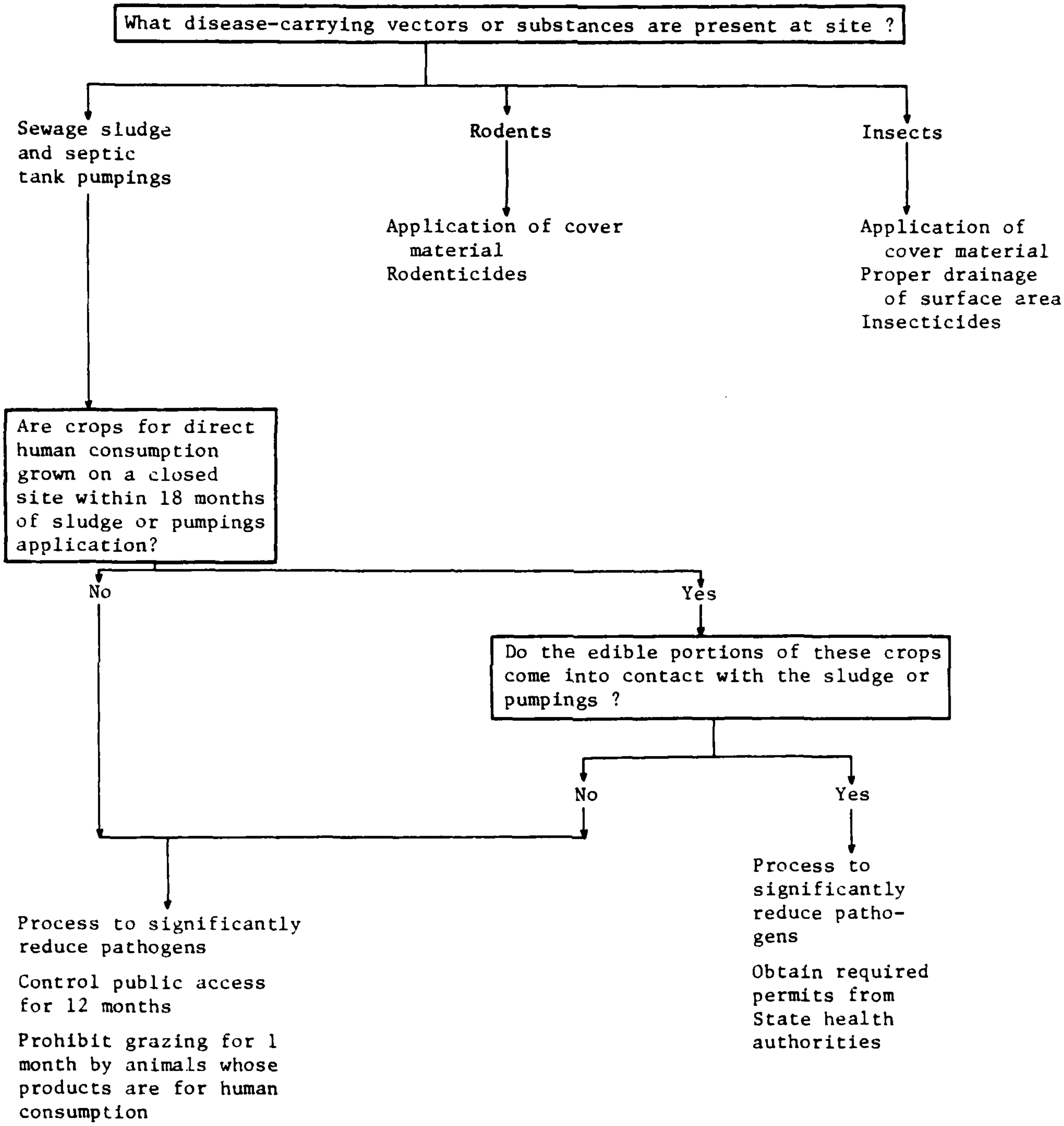

Figure 23. Decision flow for disease control technologies.

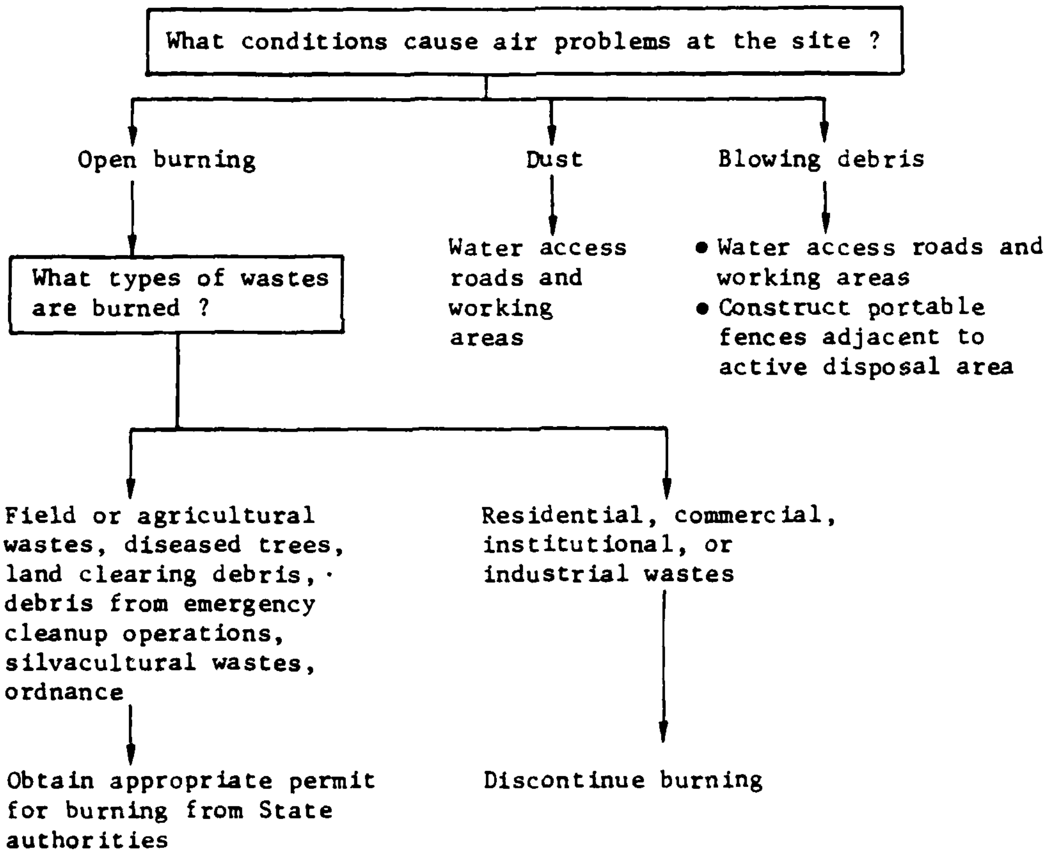

Figure 24. Decision flow for air protection techniques.

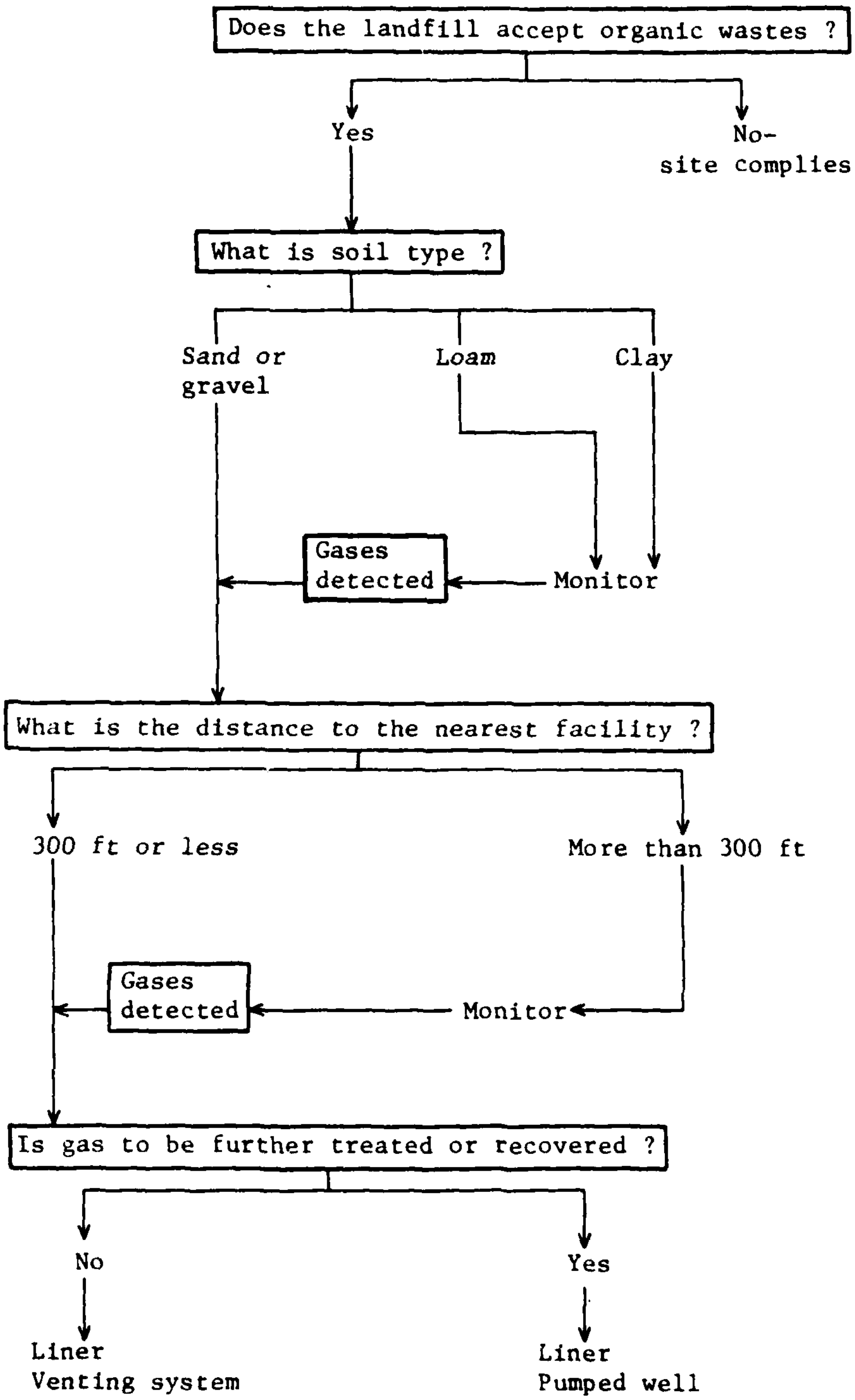

Figure 25. Decision flow for gas control technologies.

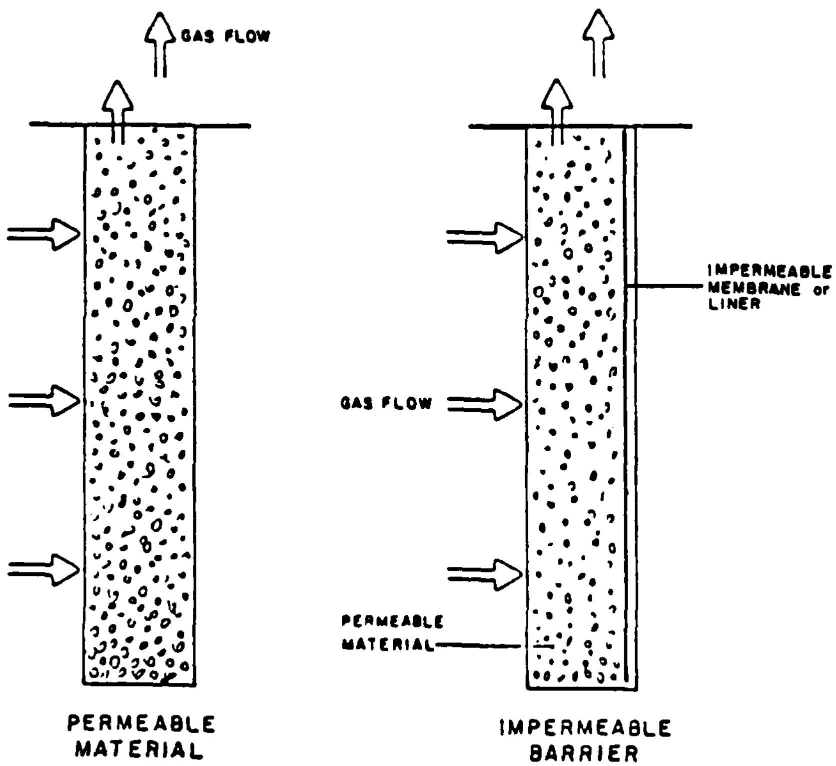

Figure 26. Liners.

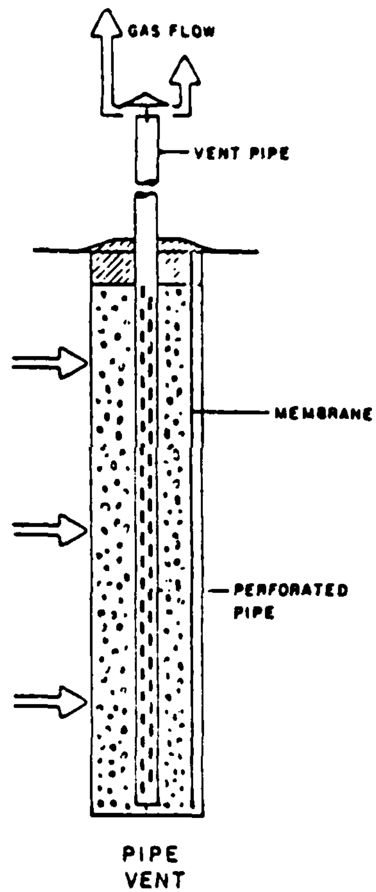

Figure 27. Venting system.

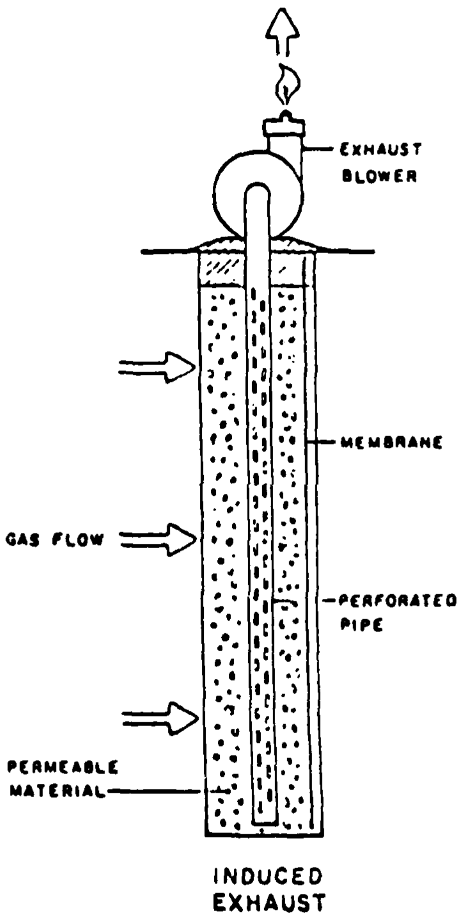

Figure 28. Pumped well.

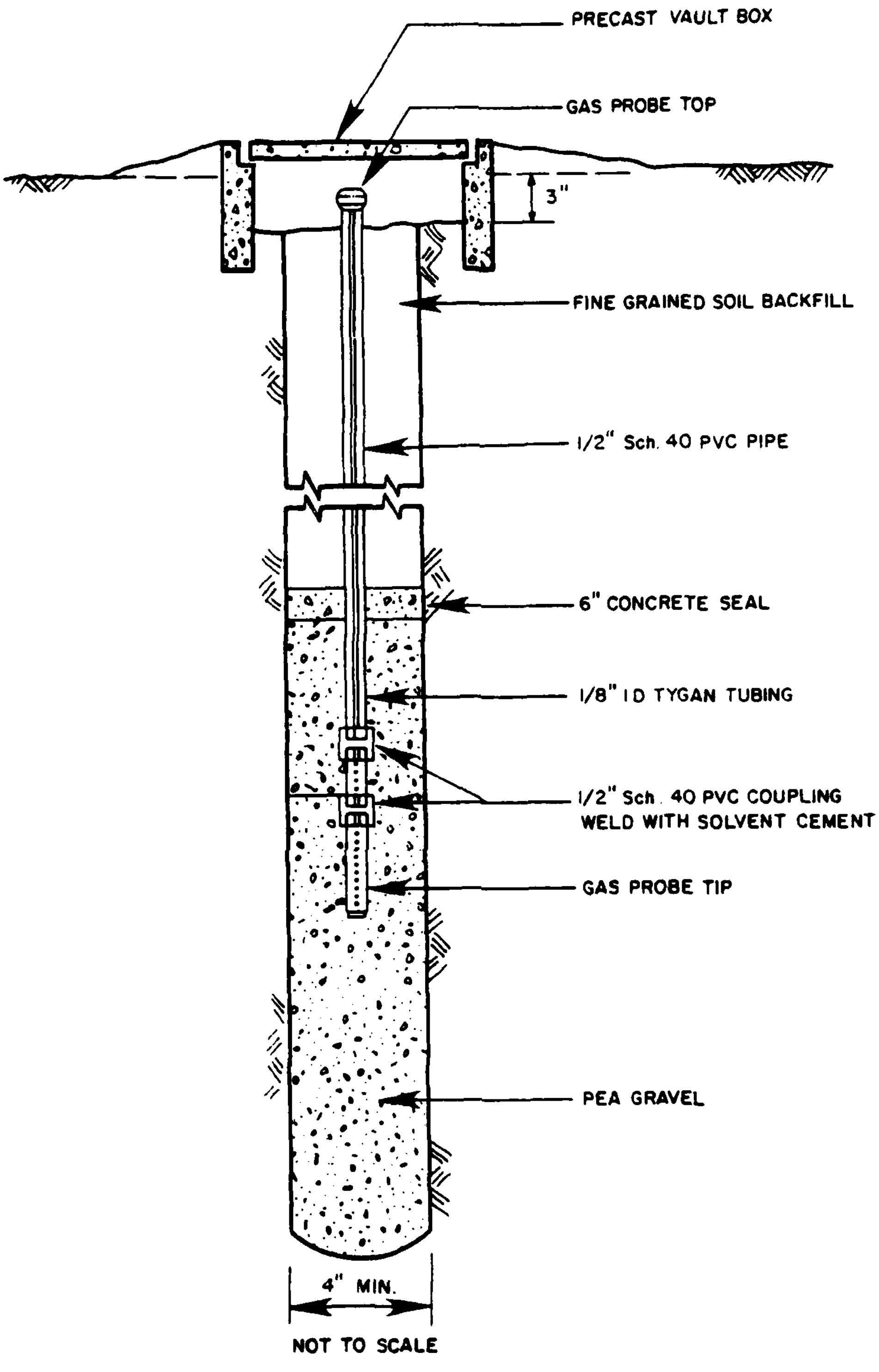

Figure 29. Typical gas probe.

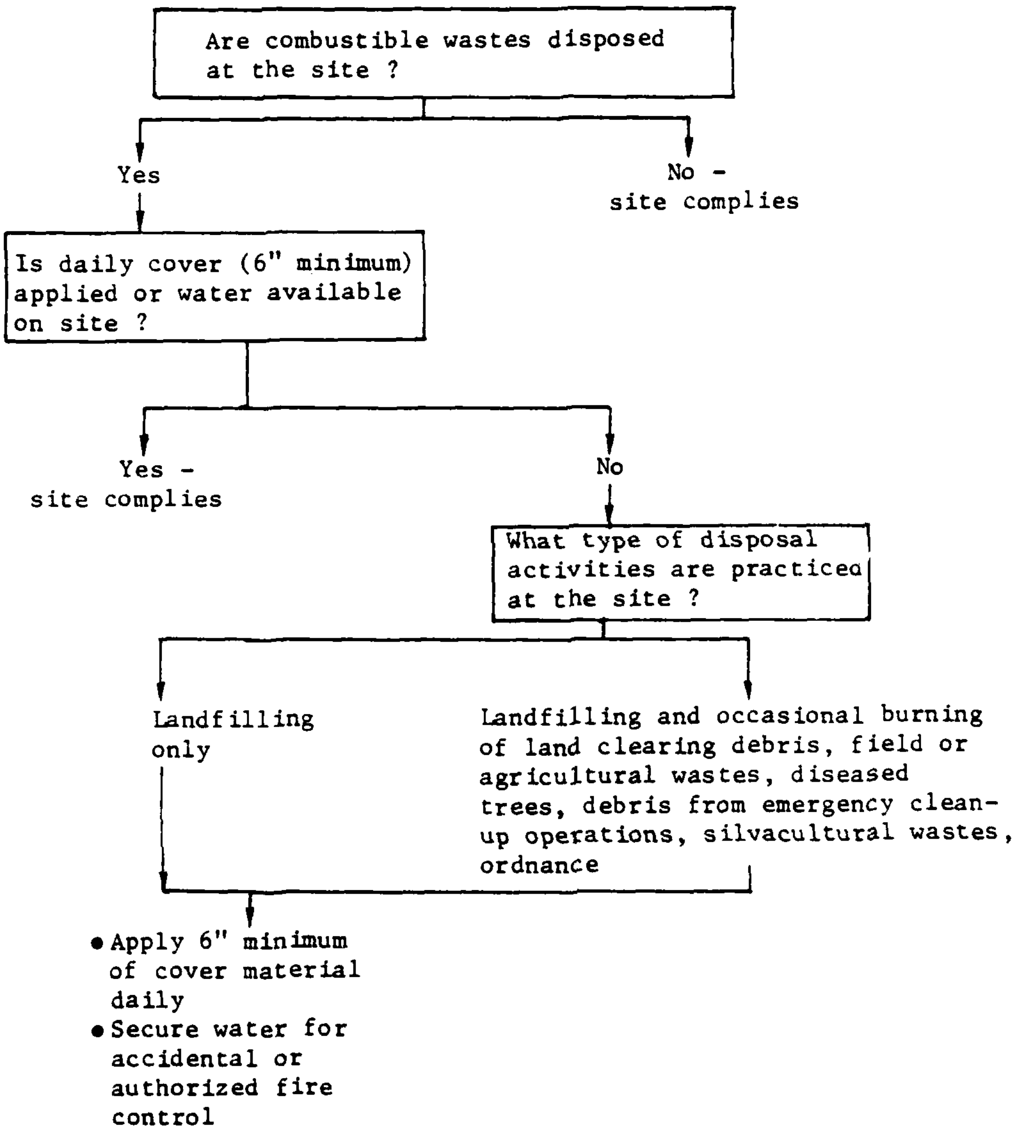

Figure 30. Decision flow for fire control technologies.

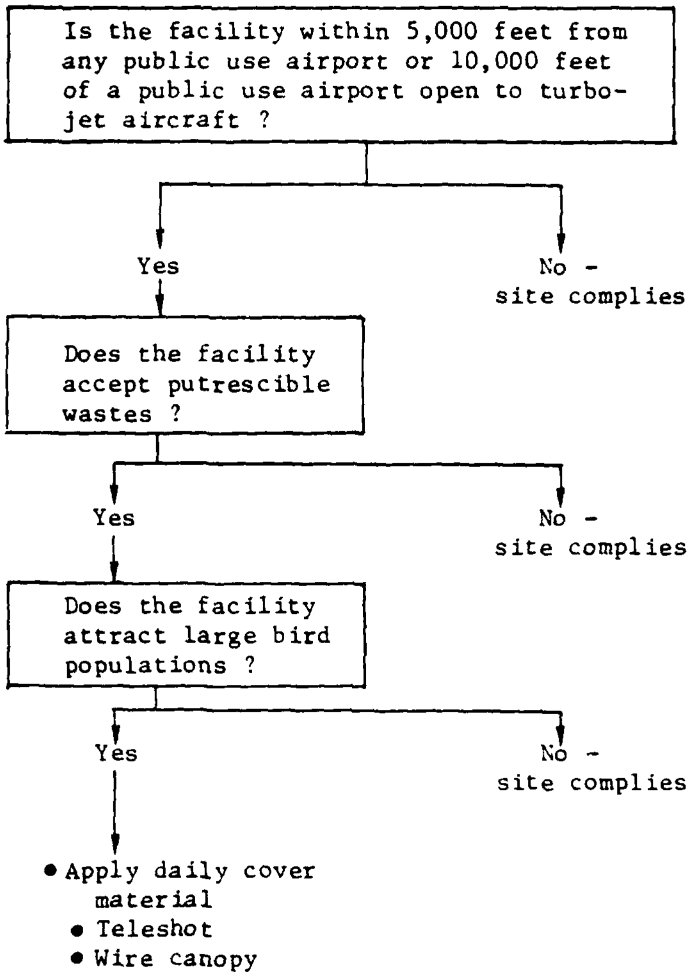

Figure 31. Decision flow for bird hazard technologies.

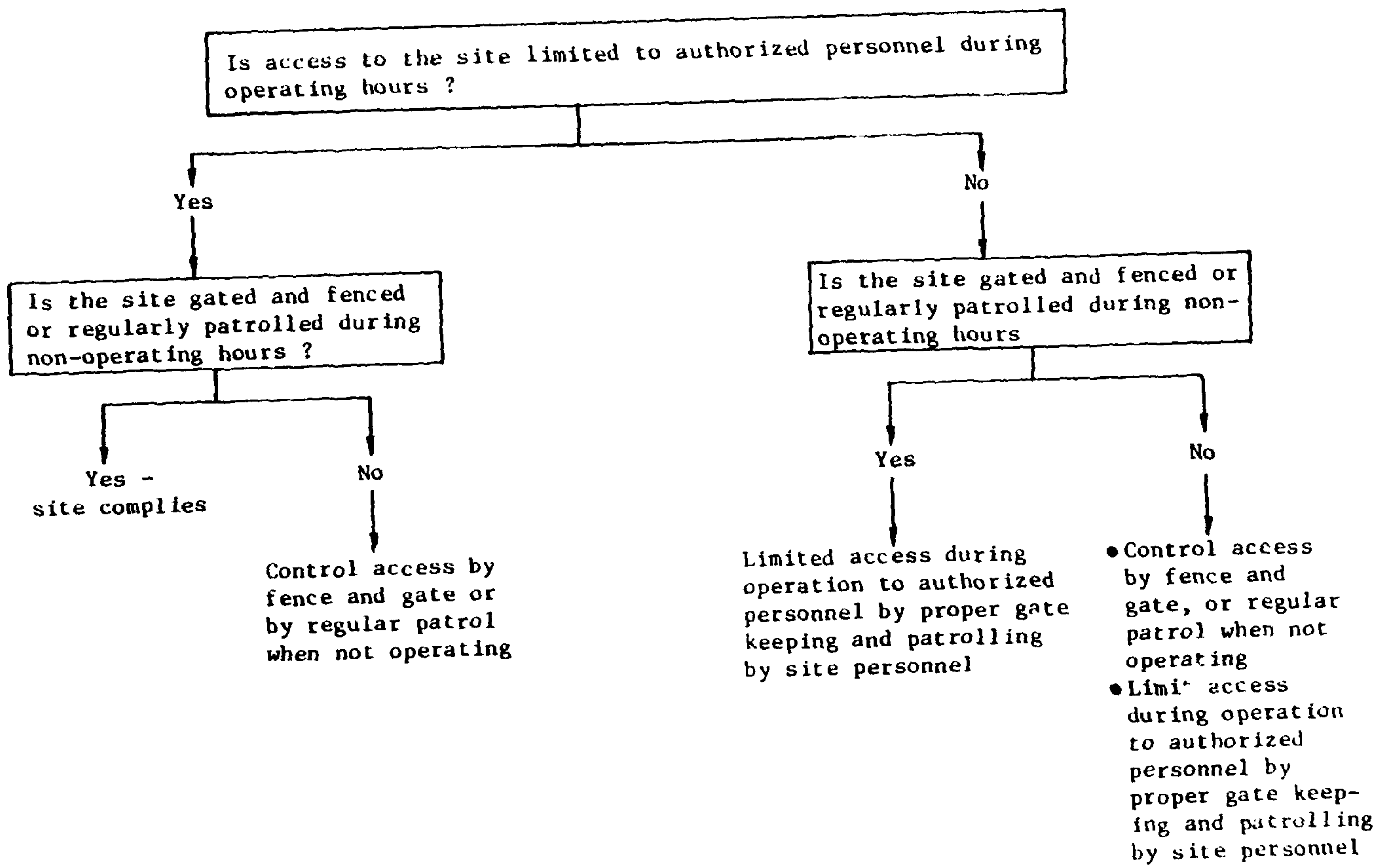

Figure 32. Decision flow for access control techniques.

APPENDIX A:

OPERATION AND MAINTENANCE COSTS FOR IDENTIFIED TECHNOLOGIES

Description	Average O&M Cost
Berms, dikes and levees	3.5% of initial capital cost
Floodwalls	4.0% of initial capital cost
Control of backwater flow	
Dredging	9% of initial capital cost
On-shore excavation	2% of initial capital cost
Ditches, diversions and waterways	6% of initial capital cost
Trenches and benches	5% of initial capital cost
Chutes and downdrains	5% of initial capital cost
Drainage systems	7% of initial capital cost
Drainage systems: trenches	4% of initial capital cost
Drainage systems: recharge	2% of initial capital cost
Sedimentation ponds and basins	4% of initial capital cost
Grading and revegetation	3% of initial capital cost
Surface capping	5% of initial capital cost
Liners	5% of initial capital cost
Slurry and clay-filled trench	2% of initial capital cost
Grouting	2% of initial capital cost
Subsurface drains	5% of initial capital cost
Dewatering	5% of initial capital cost
Extraction wells	6% of initial capital cost
Leachate collection systems	4% of initial capital cost
Leachate treatment	15% of initial capital cost
Leachate attenuation	6% of initial capital cost
Active control systems	8% of initial capital cost
Groundwater monitoring	\$400.00/sample + 1%/well of initial capital cost
Assessing potential gas hazard	\$700.00/sample + 1%/well of initial capital cost
Bird hazards: cable	4% of initial capital cost
Access: fence	4% of initial capital cost

APPENDIX B:

CREW DESCRIPTIONS AND COSTS

Crew #	Labor	Daily Cost	Equipment	Daily Cost
A-1	1 Building Laborer	$125.60	1 Gas Eng. Power Tool	$33.00
B-1	1 Foreman (outside)	148.00		
	2 Building Laborers	251.20		
B-2	1 Foreman (outside)	148.00		
	4 Building Laborers	502.40		
B-10A	1 Equip. Oper. (med)	164.00	1 Roller Compactor, 2,000 lb.	58.70
	0.5 Building Laborer	62.80		
B-10B	1 Equip. Oper. (med)	164.00	1 Dozer, 200 HP	429.90
	0.5 Building Laborer	62.80		
B-10C	1 Equip. Oper. (med)	164.00	1 Dozer, 200 HP	429.90
	0.5 Building Laborer	62.80	1 Vibratory Roller, Towed	57.20
B-10G	1 Equip. Oper. (med)	164.00	1 Sheepsfoot Roller, 130 HP	238.00
	0.5 Building Laborer	62.80		
B-10L	1 Equip. Oper. (med)	164.00	1 Dozer, 75 HP	139.00
	0.5 Building Laborer	62.80		
B-10M	1 Equip. Oper. (med)	164.00	1 Dozer, 300 HP	633.40
	0.5 Building Laborer	62.80		
B-11C	1 Equip. Oper. (med)	164.00	1 Backhoe Loader, 48 HP	133.80
	1 Building Laborer	125.60		
B-11M	1 Equip. Oper. (med)	164.00	1 Backhoe Loader, 80 HP	170.30
	1 Building Laborer	125.60		
B-12A	1 Equip. Oper. (crane)	168.40	1 Hydraulic Excavator, 1 CY	331.30
	1 Oiler	139.60		
B-12D	1 Equip. Oper. (crane)	168.40	1 Hydraulic Excavator, 3½ CY	1,087.90
	1 Oiler	139.60		
B-12G	1 Equip. Oper. (crane)	168.40	1 Crawler Crane, 15 Ton	220.00
	1 Oiler	139.60	1 Clamshell Bucket, ½ CY	27.20

Crew #	Labor	Daily Cost	Equipment	Daily Cost
B-12Q	1 Equip. Oper. (crane)	$168.40	1 Hydraulic Excavator, 5/8 CY	$224.80
	1 Oiler	139.60		
B-13	1 Foreman (outside)	148.00	1 Hydraulic Crane, 25 Ton	355.30
	4 Building Laborers	502.40		
	1 Equip. Oper. (crane)	168.40		
	1 Oiler	139.60		
B-15	1 Equip. Oper. (med)	164.00	2 Trucks, Heavy	442.20
	0.5 Building Laborer	62.80	1 Dozer, 200 HP	429.90
	2 Truck Drivers (heavy)	260.00		
B-20	1 Foreman (outside)	201.20		
	1 Plumber	178.80		
	1 Building Laborer	125.60		
B-21	1 Foreman (outside)	201.20	0.5 Self-Prop. Crane, 5 Ton	59.20
	1 Plumber	178.80		
	1 Building Laborer	125.60		
	0.5 Equip. Oper. (crane)	84.20		
B-25	1 Foreman (outside)	148.00	1 Paving Machine	427.20
	7 Building Laborers	879.20	1 Roller, 10 Ton	114.40
	2 Equip. Oper. (med)	328.00		
B-26	1 Foreman (outside)	148.00	1 Grader	300.70
	6 Building Laborers	753.60	1 Paving Machine & Equipment	932.80
	2 Equip. Oper. (med)	328.00		
	1 Rodman (reinforcing)	184.40		
	1 Cement Finisher	151.60		
B-33B	1 Equip. Oper. (med)	164.00	1 Scraper, Towed, 12 CY	105.20
	0.5 Building Laborer	62.80	1 Dozer, 300 HP	633.40
	0.25 Equip. Oper. (med)	41.00	0.25 Dozer, 300 HP	158.40
B-37	1 Foreman (outside)	148.00	1 Roller, 3 Tons	56.80
	4 Building Laborers	502.40		
	1 Equip. Oper. (light)	155.20		

Crew #	Labor	Daily Cost	Equipment	Daily Cost
C-6	1 Labor Foreman (outside)	$148.00	2 Gas Engine Vibrators	$37.85
	4 Building Laborers	502.40		
	1 Cement Finisher	151.60		
C-14	1 Foreman (outside)	178.40	1 Crane, 80 Ton & Power Tools	847.10
	5 Carpenters	782.00		
	4 Building Laborers	502.40		
	4 Rodmen (reinforcing)	737.60		
	2 Cement Finishers	303.20		
	1 Crane Operator	168.40		
	1 Oiler	139.60		
Q-2	2 Plumbers	357.60		
	1 Apprentice	142.80		
Q-7	1 Foreman (inside)	185.20		
	2 Steamfitters	359.20		
	1 Apprentice	143.60		

METRIC CONVERSIONS

1 acre = 0.41 ha
1 ft = 304.8 mm
1 cu ft = 2.83×10^{-2} m^3
1 sq ft = 9.29×10^{-2} m^2
1 gal = 4.54 L
1 gal/min = 6.31×10^{-5} m^3/sec
1 in. = 25.4 mm
1 mi = 1.61 km
1 psi = 6.9 kPa
1 ton = 0.91 MT
1 yd = 0.91 m
1 cu yd = 7.65×10^{-1} m^3
1 sq yd = 8.36×10^{-3} m^2

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